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EVALUATION OF A LOUDNESS DISCRIMINATION TEST.(U)
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EVALUATION OF A LOUDNESS DISCRIMINATION TEST

Jeane Violon Singer

Technical Memorandum
File No. TM 80-107
May 13, 1980
Contract No. N00024-79-C-6043

Copy No. 5

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NAVY DEPARTMENT

NAVAL SEA SYSTEMS COMMAND

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER TM 80-107	2. GOVT ACCESSION NO. AD-A087 101	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) EVALUATION OF A LOUDNESS DISCRIMINATION TEST		5. TYPE OF REPORT & PERIOD COVERED PhD Thesis, August 1980
(14) ARL/PSU		6. PERFORMING ORG. REPORT NUMBER TM-80-107
7. AUTHOR(s) (10) Jeane Violon Singer	(15)	8. CONTRACT OR GRANT NUMBER(s) N00024-79-C-6043
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Pennsylvania State University Applied Research Laboratory P. O. Box 30, State College, PA 16801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command Department of the Navy Washington, DC 20362	(11) 13	12. REPORT DATE May 1980 13. NUMBER OF PAGES 122 pages & figures
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 133		15. SECURITY CLASS. (of this report) Unclassified, Unlimited 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited, per NSSC (Naval Sea Systems Command), 5/27/80

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(9) Doctoral thesis

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

human, noise, loudness, perception, test

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Recent research conducted at the Environmental Acoustics Laboratory at The Pennsylvania State University has demonstrated that temporary changes in loudness perception occur following high level noise exposure. Two pilot studies and an experiment are presented in this study which evaluates a noise-induced loudness perception test. The first two experiments investigated the feasibility of several loudness perception test parameters. The third experiment described a Loudness Discrimination Growth Test (LDGT)

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S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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20. ABSTRACT (continued)

which is based on the information obtained in the first two experiments. This LDGT was evaluated in terms of clinical feasibility, reliability, and sensitivity. The findings suggested that the LDGT is reliable, is affected by the spectral content of the exposure sound, and measures noise-induced temporary auditory change that is different from a temporary threshold shift growth test. With further research, this LDGT could be incorporated into a test battery for use in identifying those individuals who are sensitive to noise-induced auditory changes possibly before they develop permanent auditory impairment.

ACKNOWLEDGEMENTS

The author wishes to express her special appreciation to Dr. Gordon Bienvenue for his inspiration, support and guidance and to Dr. Bruce Siegenthaler for his editorial assistance. The author would also like to thank her husband, Richard, and parents for their confidence and infinite patience throughout the course of this project. This research was supported by the Applied Research Laboratory of The Pennsylvania State University under contract with the Naval Sea Systems Command.

ABSTRACT

Recent research conducted at the Environmental Acoustics Laboratory at The Pennsylvania State University has demonstrated that temporary changes in loudness perception occur following high level noise exposure. Two pilot studies and an experiment are presented in this study which evaluates a noise-induced loudness perception test. The first two experiments investigated the feasibility of several loudness perception test parameters. The third experiment described a Loudness Discrimination Growth Test (LDGT) which is based on the information obtained in the first two experiments. This LDGT was evaluated in terms of clinical feasibility, reliability, and sensitivity. The findings suggested that the LDGT is reliable, is affected by the spectral content of the exposure sound, and measures noise-induced temporary auditory change that is different from a temporary threshold shift growth test. With further research, this LDGT could be incorporated into a test battery for use in identifying those individuals who are sensitive to noise-induced auditory changes possibly before they develop permanent auditory impairment.

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CHAPTER I

MOTIVATION FOR THE STUDY

Effects of Noise Exposure on Hearing

Exposure to noise at high sound pressure levels for long periods of time can produce detrimental changes in the inner ear and seriously impair the ability to hear (Miller, 1974). Many of these hearing changes are temporary. After recovery from these temporary effects, however, there may be residual permanent effects on hearing.

Evidence of the damaging effects of intense noise on the auditory system has been obtained from research applied to animals. These animal studies have shown that the outer ear, eardrum, and middle ear are rarely damaged by exposure to intense noise (VonGierke, 1965; Miller, 1974). However, excessive exposure to noise can result in the destruction of sections of the organ of Corti, and auditory neurons may degenerate (Bohne, 1976; Bredberg, Ades, and Engstrom, 1972; Miller, 1971). Injury to the organ of Corti may be manifested in a loss in hearing abilities.

There is not a direct relationship between the extent of cochlear injury and the resultant hearing handicap when the hearing is measured by threshold testing. Ward and Duvall (1971) reported that extensive loss of outer hair cells was seen in the absence of any apparent loss of hearing sensitivity. Recent evidence from human and animal experiments suggests that the loss of sensory cells in the apical part of the cochlea (low frequency end) must be quite extensive before this damage is reflected in a change in threshold. Thus, extensive cochlear injury following noise exposure has been observed in the absence of

elevation of the hearing thresholds for low frequencies. Conversely, in the basal part of the cochlea (high frequency end) losses of sensory cells of over a few millimeters may be reflected in changes in hearing (Bredberg, 1968).

The threshold changes that result from high level noise exposure typically center around 4000 Hz, and are detected as a 4000 Hz dip or notch in the audiogram configuration (Schuknecht, 1974; Spoendlin, 1976). If exposure to damaging noise continues, this notch usually becomes deeper (greater hearing loss) and spreads to include a broader frequency range (Sataloff and Michael, 1973).

The changes in hearing that follow high level exposure to noise are complicated and are not limited to threshold shift. Noise-induced hearing changes can include distortions of the clarity and quality of the auditory perception as well as loss in the ability to detect sound. The extent of these changes can vary greatly among people.

A great deal of effort has been expended in recent years by government and industry to protect individuals from potentially harmful noise exposure. Concern over noise in industry was reflected in the Department of Labor issuance of the Walsh-Healey Public Contracts Acts in 1969 and the Occupational Safety and Health Act (OSHA) in April 1972. Because of several different practical problems, the rules and regulations are not written to protect all the people from noise injury. Problems include the lack of technical knowledge of how to quiet machinery, economic impact of the laws, and inadequate procedures for measuring noise and assessing hearing impairment. Another major

problem encountered in trying to write a noise law which protects the entire population is that individuals differ greatly in their susceptibility to noise-induced hearing damage (Gallo and Glorig, 1964; Robinson, 1968; Sataloff et al., 1969).

The marked individual variation in noise susceptibility makes it difficult to establish an effective hearing conservation program. For example, if two individuals are exposed to the same noise for the same length of time, one may retain near normal hearing while the other may sustain a significant hearing loss. If a hearing conservation program is to be effective, the noise levels should be reduced to a safe level for the most sensitive individuals. Probably the allowable sound level should be no more than 70 dB(A), because some noise-susceptible individuals may be permanently injured by sustained exposures at higher levels (Michael, 1976). But the economic impact of limits set at this level would make it impossible in most situations. In addition, many recreational activities and other activities not related to the work place cause noise exposures greater than 70 dB(A), (EPA Publication, 1971). Thus, it is generally impractical to use this low level exposure limit in industry unless the normal life style of this country is changed radically.

There are no practical and accurate procedures presently known that can be used to determine noise-susceptible persons before the development of significant, permanent hearing impairment. Temporary threshold shift (TTS) testing procedures have been used with some success in research studies to provide statistical information on susceptibility to specific sound exposures, but TTS data have not proved to be efficient

for predicting permanent threshold shift in practical situations for an individual (Harris, 1965). Various methods of TTS testing are discussed later.

Investigation into a test procedure that is sensitive to noise-induced hearing changes before permanent hearing damage occurs is warranted because of the inadequacy of threshold measurement as a predictor of noise susceptibility. The primary purpose of an improved test procedure would be to identify significant but nonhandicapping hearing change that may occur prior to the development of a permanent loss in hearing sensitivity. Such a test would be valuable to identify noise-susceptible individuals and avoid their assignment to noisy work areas.

Temporary Threshold Shift

The measurement of temporary threshold shift (TTS) following a controlled noise exposure was proposed as a predictor of individual noise susceptibility (Ward, 1966). In general, the observed TTS in a person for a given noise exposure closely parallels the average permanent threshold shift (PTS) for similar exposures when large groups of subjects are studied. It has been established by a number of researchers that the greater the level of noise exposure (up to approximately 120 dB), the larger the amount of TTS (Davis et al., 1950; Eldridge et al., 1957; Ward, 1952). In addition, as the duration of the noise exposure is increased the amount of TTS is also increased (Miller, 1974). It has been observed, however, that the growth of TTS resulting from high level sound reaches an asymptotic value after 24 to 48 hours

of continuous exposure (Mills et al., 1970; Miller et al., 1971). That is, the amount of TTS increases systematically with an increase in the exposure duration of high level noise up to a critical duration. TTS measurements may be reliable for predicting permanent threshold shift (PTS) in laboratory studies which carefully control the subjects' environment, which take several measurements over an extended period of time, and which statistically calculate the risk of developing PTS. This type of test procedure, however, cannot be used in industry because it is impossible to control a given person's environment while away from the industrial setting. Also, most industries cannot afford to allow workers to take time away from work to obtain numerous threshold measures.

In 1966, Ward proposed the measurement of TTS at two minutes after noise cessation (TTS_2) as a predictor of the amount of PTS that might develop from a noise exposure. TTS_2 has predicted the general hearing effects of noise for groups of experimental animals (Sataloff and Michael, 1973; Miller et al., 1963). However, experiments designed to show the predictive value of TTS_2 for PTS in individual human cases have failed to find a relationship (Harris, 1965; Sataloff et al., 1969; Burns, 1973). Thus, the TTS_2 method of predicting noise susceptibility is, at best, effective in only some of the cases in which it is used. It is also impractical to obtain accurate thresholds at exactly two minutes post-exposure. That is, the TTS_2 measure requires that a worker be removed from the noisy work environment and placed in

a quiet sound room and accurate thresholds be obtained within two minutes. In most work situations, it is not practical to expect to accomplish this task in such a short time for a large number of workers.

The presently enforced OSHA industrial noise limits protect only a portion of the exposed population; thus, continual monitoring of the effects of high level noises is necessary. The hearing abilities of the noise exposed population must be evaluated regularly and frequently to determine the amount of permanent threshold shift each individual has developed as a result of continued exposure to high level noises. It should also be noted that TTS is only an indicator of one type of hearing change: TTS measures only reflect threshold changes which result from high level noise exposure.

Permanent Threshold Shift

An effective hearing conservation program utilizes test methods that provide data on noise-induced hearing change susceptibility before permanent hearing change begins to occur. At least, it would be desirable to observe shifts even when they are very small so that noise-susceptible individuals could be identified early and removed from the noise before sustaining a significant hearing change.

Current approaches used in assessing the effects of high level noise exposure on hearing abilities are generally based on some interpretation of permanent threshold shift (PTS) data. Several difficulties are encountered in the use of PTS methods to assess hearing impairment.

Research indicates that errors due to earphone placement and variations in subject responses could result in threshold measurement errors as high as 17 dB in the high frequencies where noise induced PTS first appears (Atherly et al., 1963). Thus, before one can be sure that the change in threshold data reflects changes in hearing abilities, a high frequency threshold shift approaching 17 dB must be observed. It would be desirable to detect changes in workers' hearing abilities before they develop this much permanent threshold shift. Monitoring threshold hearing tests should be administered frequently if noise-susceptible individuals are to be identified before a great deal of noise-induced hearing impairment is incurred by workers with high noise exposures. However, effective threshold monitoring tests are not done in many work places because of economic and other practical considerations.

Because of complicating factors such as temporary threshold shift, it is necessary that each individual not be exposed to high level noise for at least 16 hours preceding the monitoring threshold test. This presents additional scheduling problems and may limit the number of workers tested each day.

One of the major disadvantages of a threshold monitoring program is that it identifies noise-susceptible individuals after the fact. The presence of a sizeable PTS following a minimal noise exposure alerts the hearing conservationist that a noise-susceptible person has been exposed to noise, but it only provides this information after a permanent hearing change has occurred. The post hoc nature of monitoring

audiometry is obviously inadequate for use in prevention of beginning PTS. Due to this problem, the information obtained with any PTS procedure will provide data too late to prevent noise-induced threshold changes. Thus, a PTS measurement procedure is not a desirable tool for the examination of noise susceptibility in programs for hearing conservation that intend to identify the problem before permanent damage is done.

Another problem with the PTS approach is that it only characterizes one type of auditory change (threshold shift) that can result from high level noise exposure. In addition to a hearing threshold change, persons with noise-induced hearing impairment often demonstrate abnormalities of loudness perception and loudness discrimination. These loudness abnormalities are in many cases independent of the amount of loss in hearing threshold. Animal research gives support to the theory that considerable distortion in loudness perception may be experienced prior to the development of PTS (Bredberg, 1968).

A diagnostic test procedure would measure a parameter of noise-induced hearing change that may vary independently of threshold. However, it is unlikely that a single, clear-cut predictive tool for the identification of a noise-induced hearing pathology can be found. This problem is not new to the field of clinical audiology. From clinical experience, it is known that the observed predictive efficiency of a single test is usually far lower than the efficiency of a battery of tests. The effectiveness of a test battery is even greater if the component tests of a battery do not show a high correlation among one another and thus do not duplicate the findings. Therefore, it is

appropriate that a test battery be developed which incorporates the measurement of loudness abnormalities and of temporary threshold shift. The remainder of this section will provide background material for a test of loudness abnormality.

<u>The Loudness Recruitment Phenomenon</u>

The presence of non-linearities in the perception of loudness by patients with noise-induced hearing loss was first noted by Haberman (1890). The phenomenon was named recruitment by Fowler (1936) and was defined as an abnormally rapid increase in loudness as sound intensity increases. Although a signal that gradually increases in intensity is normally perceived as increasing in loudness, the ear which exhibits recruitment shows a more rapid rate of increase in loudness than the normal ear. A person with recruitment also experiences extreme annoyance for loud sounds and a decreased range of sound levels that are comfortable for listening.

In 1948, Dix, Hallpike, and Hood demonstrated that the recruitment phenomenon was limited to cases of cochlear pathologies. They noted that recruitment very seldom occurred in persons with VIII nerve tumors while recruitment was typically seen in patients with Meniere's disease. In 1950, Mygind suggested that the recruitment phenomenon is indicative of structural damage to the cochlea or to a conduction impairment within the cochlea. Harris (1953) supported this view by noting that those pathologies showing loudness recruitment involve some mechanical damage within the cochlea as contrasted to a strictly neural

dysfunction. Thus, although the specific cause of recruitment has not yet been identified, it has been suggested that recruitment is a pathological manifestation caused by structural injury to the cochlea (Harris, 1953; Dix, 1965).

It has been known for some time that recruitment accompanies noise-induced PTS (Hardford, 1967; Graham, 1967). The question of how useful recruitment measurements are as tools for predicting noise-induced PTS has not yet been answered. In regard to this question, a study reported by Bekesy (1960) is of interest. After unilateral high level pure tone exposure, the subject demonstrated TTS as well as loudness recruitment. The TTS lasted for only 10 to 15 minutes; however, evidence of recruitment persisted for the remainder of the experiment (over one month). Thus there is evidence that noise exposure can give rise to loudness recruitment and that long term recruitment can develop following a noise exposure that causes only brief TTS and no observable PTS. It appears, therefore, that a recruitment measurement may have promise as an indicator of noise-induced hearing change.

A study completed at The Pennsylvania State University Environmental Acoustics Laboratory investigated tests of Temporary Threshold Shift (TTS) and Loudness Discrimination (LD) change following high level sound exposure as tools for early detection of hearing effects (Bienvenue et al., 1976). The results showed that the ability to detect changes in sound levels became more sensitive following brief high level noise exposure. The change in LD scores following noise exposure

was more stable with time and persisted longer than the TTS. The data also suggested that LD shift could be measured following noise exposures that are too brief or too low in level to elicit measurable TTS. Thus, in some cases LD shift (LDS) may be a more suitable method for identifying noise-induced hearing change than TTS. In view of these findings, development and evaluation of a practical and sensitive loudness discrimination test procedure is warranted.

Measurement of Loudness Recruitment

Clinical techniques for detecting the presence of loudness recruitment were originally based upon the method of loudness balancing. In this procedure, a patient compares the loudness of a tone presented at an ear that shows normal hearing with a tone presented at an ear for which the patient has an impaired hearing threshold. Loudness comparisons are performed at suprathreshold levels and the patient is instructed to adjust the level of one of the tones until it matches the loudness of the other tone. The tones are presented alternately so that the patient can listen to the tones independently as he makes his loudness comparisons. This loudness balancing task may be accomplished in the same ear, using two different test tone frequencies ((the monaural loudness balance (MLB); Reger, 1936)) or at both ears with the same tone frequency in each ((Alternate Binaural Loudness Balancing (ABLB); Fowler, 1936)).

The ABLB is used to measure recruitment when the hearing loss is unilateral (when one ear has normal hearing). In this test the patient adjusts the level of the tone presented to one ear (either pathological

or normal) to match the loudness of the same frequency of tone presented to the opposite ear. In the absence of loudness recruitment the difference in hearing level between the ears at threshold remains constant as the sound level is increased. When there is loudness recruiment, however, the difference in hearing level setting between the normal ear and the hearing impaired ear diminishes as the stimulus level is increased.

The MLB is used when it can be assumed that hearing in an ear at a particular frequency is normal. This test is performed in a manner similar to the ABLB. However, instead of balancing the loudness of two tones of identical frequency when presented to opposite ears, the patient balances two tones of different frequency presented to the same ear.

There is a serious problem with both of these tests of recruitment when examining a noise-exposed population. The ABLB requires that the patient have one normal ear, but a noise-induced hearing loss is typically a bilateral condition. Even in the rare case where only one ear shows a threshold hearing loss, the assumption that the noise exposure did not have any affect on the presumably normal ear is questionable because both ears were exposed to the noise. Thus, application of the ABLB to the noise-exposed population requires that the tester make assumptions that are not only untestable but also unlikely. The MLB requires normal hearing at one frequency and, consequently, it can be used only in cases with frequency specific bilateral hearing loss. Unfortunately, hearing impairment resulting from noise exposure may

ultimately affect most of the frequency range of hearing (Sataloff et al., 1969; Gallo and Glorig, 1964). In the 1960 Bekesy experiment previously mentioned, it was shown that recruitment may occur following noise exposure even when no threshold shift can be measured. Thus, it cannot be assumed that an ear demonstrating a normal hearing threshold at a specific frequency has normal loudness perception of discrimination at that frequency.

In summary, neither the ABLB nor the MLB tests are suitable for measuring recruitment in the noise exposed population. Because these direct tests of recruitment have limitations for use with the noise exposed population, a loudness discrimination test (i.e., an indirect test of recruitment) is better for this purpose.

Measurement Loudness Discrimination

The loudness difference limen (DL) refers to the smallest change in the intensity of a signal which the ear can detect. Two basic stimulus presentation methods have been used for measuring the difference limen: (1) the comparison of a test tone, which is varied in intensity, with a fixed reference tone separated from the test tone by a silent interval (Dimmick and Olson, 1941; Denes and Nauton, 1950), and (2) the detection of an amplitude modulation of a given single tone (Riesz, 1928; Luscher and Zwislocki, 1949). (The SISI test procedure developed in 1959 will be discussed later.) Luscher (1957) pointed out that these two methods may be measuring two distinct kinds of difference limen. He described studies by Pirodda and Zwislocki (1952) showing a positive correlation between the two measures of difference limen by the

amplitude modulation method and criterion measures of loudness recruitment. When the DL is used as a measure of recruitment, the DL of a patient is compared to a normal loudness difference limen. Much work has been done in trying to establish a criterion size for the normal difference limen. Thus, if a patient's difference limen is smaller than normal, it would be concluded that he suffers from loudness recruitment. Although Hirsh, Palva, and Goodman (1954) observed that there is too much overlap in DL size between recruiting and nonrecruiting listeners to use difference limen to differentiate between these two groups, researchers found that the DL test has a high correlation with the results of loudness balancing tests of recruitment in monaurally impaired listeners (Jerger, 1961; Owens, 1965; Kanig, 1962).

The SISI Test

In 1959, Jerger, Sheda, and Harford developed the short increment sensitivity index (SISI) as an approach to measuring the ear's ability to detect small intensity changes, although they preferred not to call the phenomenon recruitment. In the SISI test, a pure tone is presented to one ear of a subject at a 20 dB SL. A small increase in intensity is superimposed upon the steady-state tone at 5-second intervals. The size of this increment is varied from 5 dB to 1 dB in 2 dB steps. There is general agreement that in the high frequencies, the SISI test presented at 20 dB SL appears effectively to differentiate between patients with a cochlear lesion and normal hearing patients.

Jerger (1962) found that the ability to detect small changes in loudness is peculiar to disorders of the cochlea.

The SISI test is obviously different from the DL test of Luscher and Zwislocki because the patient's precise difference limen for intensity (DLI) is not explored. The measurement of the DLI is considered to be an indirect test of recruitment. Because the SISI is a modification of the DLI, the SISI was assumed to also be an indirect test for recruitment.

Martin and Salos (1970) conducted a study on subjects with unilateral cochlear pathologies. Their findings suggested that when the SISI test is performed at 55 to 65 dB SPL in either normal or cochlear impaired ears, a high score results. This study effectively demonstrated that the SISI is not an indirect test for abnormal recruitment. However, the SISI can be considered a direct test of the ear's ability to detect small intensity changes at suprathreshold levels. The SISI test has been used in many clinics as part of a differential diagnosis test battery to identify patients with cochlear lesions, a probably valid and helpful function. Thus the equipment is available and most audiologists are familiar with the test procedures.

STATEMENT OF THE PROBLEM

Marked individual variations in noise susceptibility make it difficult to establish an effective hearing conservation program. At the present time, there are no practical and accurate procedures that are used to determine noise-susceptible persons before the development of significant, permanent hearing impairments. Thus, it is appropriate to

investigate test procedures that may be sensitive to noise-induced hearing changes other than those reflected by threshold measures and that possibly occur prior to the development of a permanent loss; a measurement of the loudness function appears promising.

It is the purpose of this project to evaluate a procedure to identify changes in loudness discrimination or perception believed to follow noise exposure and present before the effects of noise exposure are permanent or obvious by the usual threshold tests for pure tones.

The evaluation will be for:

1) Clinical feasibility of the procedure (e.g., test time, ease of administration, equipment needed and ease of interpretation).

2) Reliability of a loudness discrimination test.

3) Response to a loudness discrimination test as a function of spectrum of the noise exposure.

4) Relationship between temporary noise-induced changes in loudness discrimination and temporary noise-induced change in threshold.

The project involved three sequential and cumulative experiments. The first two are to be considered pilot studies for the third experiment. A LD procedure based on the finding of these three experiments is presented (Appendix C), along with suggested acceptance criteria for its clinical use and reliability measures.

CHAPTER II

EXPERIMENT I: PILOT STUDY FOR LDI TEST PROCEDURE

Objectives

Experiment I was conducted to determine the following:

a) Usefulness of the instrumentation necessary to measure the LD function.

b) The size of the increment magnitudes for the LD test.

c) The time required to obtain an LD measure.

d) The requirement for the subject to acclimate to the change in increment magnitude.

Six males and four females with normal hearing sensitivity were selected from the The Pennsylvania State University Environmental Acoustics Laboratory listeners pool as subjects in this experiment. All were between 20 and 35 years of age, had normal hearing, and were trained and experienced listeners for psychophysical listening experiments conducted by the Laboratory.

Procedure

A loudness discrimination (LD) measure was obtained on these ten subjects using the following procedure. The listener was instructed that he/she would hear a continuous tone that would grow in loudness periodically for a brief instant. The subject was told to signal the tester by raising his/her hand when this increment in loudness of the sound was heard. The subjects were further advised that the relatively

large increments heard at first would decrease in magnitude and, eventually, the increments in the sound might resemble a warble tone. The subject was told that these warble tones would finally disappear and sound like a steady-state tone.

A 4000 Hz tone was presented to one ear of the subject at a level of 50 dB HL from a Beltone SISI adapter that was modified to produce increments in the tone of 0.5, 0.75, 1.0, 1.5, 2.0, and 3.0 dB. Each increment had a 50 msec rise and fall time with a plateau duration of 200 msec. These increments were presented at five-second intervals. The subjects were presented with ten test items at each of the six increment magnitudes. That is, each subject was first presented ten increments (one every five seconds) of 3.0 dB and the percentage of increments correctly identified was recorded. The SISI adapter was switched to produce increment of 2.0 dB, ten more items were presented, and the percentage of correct responses was recorded. This procedure was repeated with each increment magnitude in descending order until ten increments of 0.5 dB were presented.

Results

The following general results were obtained; formal tabular presentation of the test scores does not seem necessary because of the very preliminary nature of this first study. The implication of each result for the next study is given.

Several subjects were able to identify some of the increments at the 0.5 dB magnitude. Thus, the smallest increment magnitude used was

too large to obtain a zero response level. The LD function cannot be completely characterized unless smaller increment magnitudes are available to test subjects.

LD scores between 0% and 100% were usually obtained at only three of the test increment magnitudes on a subject (i.e., 0.5, 0.75, and 1.0 dB), and ceiling effects were noted at other increment magnitudes. For example, if the subject could hear 100% of the increments at a magnitude of 1.0 dB, he/she was also able to identify all the presentation at magnitudes 1.5, 2.0, and 3.0 dB. When multiple LD functions are to be collected on a subject, test time could be reduced if the number of increments examined could be reduced. Because the increment magnitudes were present in descending order (3.0 dB through 0.5 dB), the test time could be reduced by starting the LD test, for the second run, at the smallest increment magnitude that the subject identified 100% of the time on the previous run. However, the subject's complete LD function must be measured before this starting point can be determined.

Further time could be saved if the tests were stopped after the first increment magnitude that failed to elicit a response. Increment magnitudes of 0.5 dB were too small for some subjects to detect and thus it can be inferred that they would not be able to identify changes in loudness of less than 0.5 dB. Consequently, it would not be necessary to test these subject's responses to increments smaller than 0.5 dB on that test run.

In this study, approximately six minutes were required to obtain a single LD function. If the test time were decreased by implementing

the procedural changes mentioned above, it might be possible to administer multiple LD test in one sitting rather than to give the subject a rest break after each test run, as was done.

Several item presentations were required for the subject to get acclimated to listening to the increment magnitude each time the magnitude was decreased. For example, when the increment magnitude size was changed from 1.5 dB to 1.0 dB, the subject may have missed the first three presentations and then may have identified the next seven presentations correctly to obtain a score of 70%. If an additional three increments were presented at the 1.0 dB magnitude, this subject would probably have been able to identify them. Thus, a 100% score would most accurately reflect the actual ability to detect increments of a 1.0 dB magnitude. To eliminate this acclimation problem in future studies, the subjects should be presented with practice increments at each magnitude followed by the test items. The percentage of items correctly identified within the count period (last ten items) should be recorded as the score for the increment magnitude. This procedural change should provide for acclimation and minimize the actual test time used in future experiments.

Conclusions

Some subjects had difficulty initially becoming aware of the changes in loudness early in the test. To account for learning effects, a Loudness Discrimination training session would be helpful before experimental data collection.

The experimentor's impression is that the timing of the increment presentations should be changed from one presentation every five seconds to a randomized time sequence. This modification should reduce the chance of subjects correctly guessing when an increment would be presented and giving a false response. The anticipation of when a test stimulus was about to occur was observed in several subjects.

Based on the information obtained in Experiment I, it was concluded that the following modifications in data collection procedures should be made:

1) The presentation of the increments should be separated by time intervals that randomly vary between 2.5 and 5 seconds.

2) The range in size of the increment magnitudes should extend to less than 0.5 dB.

3) A practice LD function should precede actual data collection.

4) The test time should be shortened by eliminating increment sizes obviously producing 0% or 100% after such a score is obtained on a subject for a given increment size.

5) Up to five practice increments at each magnitude should be presented if necessary before the subject's responses are recorded.

CHAPTER III

EXPERIMENT II: PILOT STUDY FOR LD GROWTH TEST PROCEDURE

Objectives

Experiment II investigated the feasibility of measuring the growth of LD shift following short exposure to high levels of sound. The general plan was to obtain an LD measure, expose the subjects to a noise, and immediately obtain an LD post-exposure measure and threshold. The subjects were then exposed to a louder noise, followed immediately by an LD and threshold measure. This noise exposure/post-test paradigm continued over a range of noise exposure levels. In this type of test, the subject's post-exposure change in LD function (LD growth) and threshold shift can be charted. The subjects for this experiment consisted of 14 females and 6 males under 35 years selected from the Environmental Acoustics Laboratory listening pool by randomly choosing names until 20 willing listeners were obtained.

Procedure

In this experiment, each subject's history of noise exposure was obtained using the case history shown in Appendix A. The case history data were used to classify the subjects into two groups (noise-exposed and non-noise-exposed). If the subjects answered yes to questions 4, 15, or 16 or had a noisy second job and/or hobby, he was classified as noise-exposed. The LD information was analyzed for each group. Thresholds were obtained on all subjects at octaves 250 Hz through 8000 Hz to insure that all subjects had normal hearing (thresholds

20 dB or better). An LD function was obtained in one ear (randomly selected) of each of the 20 subjects at 4000 Hz. All the exposures and tests in this experiment were presented to the same ear of a subject, designated as the test ear. The LD function was measured at 50 dB HL using increments of 3.0, 2.0, 1.5, 1.0, 0.8, 0.6, 0.4, 0.2, and 0.1 dB magnitude. The number of test stimuli identified for a given increment magnitude was recorded beginning with 3.0 dB and working down sequentially until the subject was unable to identify any of the increments at a given magnitude. This LD test procedure was performed twice before the noise exposure. The first LD test was used as a training session, and the second LD test was recorded as the pre-test.

The method used to score the LD function was based on the revised procedure advocated in the previous experiment. That is, up to five test items were presented in a practice session at each increment magnitude. The recording of responses began with the first increment that the subject correctly identified within the first five, or with the sixth item if none of the first five were identified. A total of ten test items was presented, at each increment magnitude, beginning with the first response counted. The number of test items (of ten) correctly identified, at each increment magnitude, was recorded.

Following this LD measure, the subject was exposed to a 2000 Hz tone at 80 dB for five minutes in the test ear. Immediately after this exposure, the subject's LD functions was again recorded at 4000 Hz using the same presentation levels that were used in the pre-exposure test. The post-exposure test began with the smallest increment magnitude at which the subject had obtained a 100% score on the

previous test. Following the LD measure (completed approximately three minutes post-exposure), the subject's threshold at 4000 Hz was obtained (lowest level for two out of three responses, ascending only technique). The sound exposure, the LD function, and threshold were repeated five times in one session, with an increase in the exposure level of 5 dB for each trial until an exposure of 105 dB was reached. Thus, the LD test was administered to every subject after sound exposure levels of 80 dB, 85 dB, 90 dB, 95 dB, 100 dB, and 105 dB. To avoid complicating effects of exposure to high level sounds, such as large temporary threshold shifts and tinnitus, 15-minute breaks were taken after the LD measurements obtained following the 95 dB and 100 dB exposure tones. After at least 24 hours post-exposure, the pre-test LD sequence was repeated on the test ear of each subject.

The test procedure in this experiment was set up in accordance with the Table 1 format (for the sound exposure condition).

Results

The information obtained in this second experiment was analyzed in the following manner. The pre-exposure threshold value at 4000 Hz was subtracted from the post-exposure threshold value at 4000 Hz to obtain a temporary threshold shift (TTS) measure for each exposure level, and the mean dB shift across the 20 subjects was calculated. The LD shift scores (LDS) were calculated by subtracting the pre-exposure LD scores from the post-exposure LD scores at each respective increment magnitude and for each exposure level. The LD shift scores were then analyzed in terms of the mean change (across the 20 subjects) at each increment

Table 1. Experiment II Test Procedure
for the Sound Exposure Condition

Exposure	Tests Done
2K Hz tone for 5 min at 80 dB	LD at 4K Hz and threshold at 4K Hz
2K Hz tone for 5 min at 85 dB	LD at 4K Hz and threshold at 4K Hz
2K Hz tone for 5 min at 90 dB	LD at 4K Hz and threshold at 4K Hz
2K Hz tone for 5 min at 95 dB	LD at 4K Hz and threshold at 4K Hz
15 minute rest period	
2K Hz tone for 5 min at 100 dB	LD at 4K Hz and threshold at 4K Hz
15 minute rest period	
2K Hz tone for 5 min at 105 dB	LD at 4K Hz and threshold at 4K Hz

magnitude for each exposure level. At increment magnitudes of 2.0 dB and 3.0 dB, all subjects obtained an LD score of 100% for both the pre- and post-exposure LD test; the 3.0 dB increment magnitude was discarded as a redundant measure that provided no additional information, and a total of 48 means was analyzed (eight increment magnitudes over the six exposure levels). If a subject was not tested, for example, at the 2 dB increment because previously he had obtained a score of 100% at that level as well as the next smaller LD level, the score for 2 dB was taken to be 100%.

The LD Index (LDI) was also examined in this analysis. The LDI is the largest LD shift observed following a given exposure level for any of the increment magnitudes. Specifically, the number of increments (out of ten) correctly identified was recorded for each subject at each increment magnitude for the pre-exposure data and post-exposure data. The pre-exposure data was subtracted from each exposure level at every increment magnitude. The largest difference score that appeared for each subject at each exposure level was considered that subject's LDI for the respective exposure level. The LDI is a desirable parameter because it avoids the problem of specifying a particular LD increment magnitude. That is, some subjects may experience their highest LD shifts at large increment magnitudes, while others will show their largest LD shifts at small increment magnitudes. The LDI can be considered the most sensitive measure of change in the LD function because it represents the largest LD shift that occurred, regardless of the increment magnitude at which it occurred. Thus, the LDI value was obtained to minimize data variance introduced by individual differences

in baseline LD functions and to avoid the problem of specifying a particular LD increment magnitude.

The data were analyzed first in a two-way analysis of variance. This experiment has a two-factor repeated measures design with eight levels of the increment magnitude factor and six levels of the exposure level factor. The data entered into the cells of this analysis were LDS data.

The approach to the analysis of variance is that recommended by Myers (1972) for a repeated-measures design. Myers identified the mean-square for a given main effect as containing the variability due to error of measurement, the variability due to the interaction of the factor being tested with subjects, and the variability due to the mean factor being tested. This is accomplished by combining data across other factors in the design. An error term is used to test the significance of the main factor effect by performing an F test. The error term contains the variability due to error of measurement and the variability due to the interaction of the factor being tested with subjects. Note that one component of the error term is the interaction of the factor being tested with subjects. For this reason, the error term used to test each factor in the analysis varies with the factor being tested, leading to a different error term for each F ratio. The same approach is used in testing interactions. In this case, the error term is derived from the combination of the individual subject variability and the interaction of subjects with the main factors being examined. For more complex, repeated-measures design, the same approach is used but it is expanded to include more main factors.

The results of this analysis are shown in Table 2.

There was a significant exposure level by increment magnitude interaction (ELxIM). This interaction is due to the structure of the LD growth test. Specifically, at large increment magnitudes, subjects identified most of the test items in the pre-test as well as the post-test, resulting in small LDS scores. This same type of ceiling effect occurred at the small increment magnitudes where the subjects missed most of the test items in the pre-test and post-test. In the mid-range increment magnitudes, the subject LDS increased as the exposure sound increased. Thus, as the exposure sound increased, the subjects showed small LDS for the large increment magnitudes, large LDS for the mid-range increment magnitudes, and small LDS for the small increment magnitudes. This resulted in an ELxIM interaction.

The F ratio for the EL factor indicated that there was a significant shift in the LDS function across exposure levels; the LDS pooled across the increment magnitudes increased significantly as the exposure level was increased.

The F ratio for the IM factor was also significant. When the data for the respective increment magnitudes were pooled across all the exposure levels, the LDS scores changed significantly across the different increment magnitudes.

A Newman-Keuls follow-up test of minimal differences was performed on the main effects of the exposure level factor to determine the lowest exposure which resulted in the significant shift. The results of this analysis are shown in Table 3. Using Duncan's underlining technique (1955), the means that are underlined are not significantly

Table 2. Analysis of Variance Summary Table for Experiment II: Difference Limen Shift Data with Factors of Increment Magnitude (N8) and Exposure Level (N6)

Source	Mean Squares	Degrees of Freedom	F Ratio	Significance Level
Between Subjects				
Error	2263.254	20		
Within Subjects				
Exposure Level (EL)	3202.540	5	16.137	<0.001
Error	198.456	100		
Increment Magnitude (IM)	5142.177	7	8.522	<0.001
Error	603.367	140		
Interaction (ELxIM)	412.789	35	4.787	<0.001
Error	86.230			

Table 3. Mean LDS Scores Following a Five-Minute 2000 Hz Exposure

	Exposure Level (dB)					
	80	85	90	95	100	105
*Mean LD Shift Score	.0892	.375	.613	1.030	.958	1.238

*Values connected by underline are not significantly different from each other at 0.05.

different from one another at the .05 level. The mean LD shift scores listed in Table 3 were pooled across the 20 subjects and across all the increment magnitudes. The first significant difference in LDS scores occurred following the 90 dB exposure. Note that the means in Table 3 are listed in ascending value and not according to the exposure level. The general trend of the mean LD shift scores shows an increase in the mean LD shift scores as the level of the exposure sound is increased. The mean LD shift score decreases from the 95 dB exposure to the 100 dB exposure; however, this decrease is not a significant change (not significant at 0.05).

A one-factor analysis of variance was calculated on the LD Index (LDI) data at each exposure level. As previously noted, the LDI is the largest LD shift observed for any of the increment magnitudes. A summary of the results of this analysis is shown in Table 4.

The F ratio was significant at the 0.001 level indicating that there is also a significant change in the LDI shift score (across the 20 subjects) when the LDI data were used. A Newman-Keuls test was used to examine the main effect of LDI data. The results of this follow-up test are shown in Table 5 employing Duncan's underlying technique.

The first significant shift in the LD function occurred following the 85 dB exposure noise when the LDI data are used. Thus, the LDI data indicate a significant change at a lower exposure level than the LDS data averaged across the increment magnitudes.

The TTS data following each exposure level were also analyzed in a one factor analysis of variance. The results of the calculation is shown in Table 6. There is a significant F ratio. As exposure level

Table 4. Experiment II: Analysis of Variance Summary Table; LDI Data at Exposure Level

Source	Mean Squares	Degrees of Freedom	F Ratio	Significance Level
Between Subjects				
	2813.175	19		
Within Subjects				
Exposure Level	2776.508	5	10.604	<0.001
Error	261.841	100		

Table 5. Mean LDI Scores Following 2000 Hz Exposure

	Exposure Level (dB)					
	60	85	90	95	100	105
*Mean LDI Scores	.666	1.905	2.476	3.238	3.000	3.952

*Values connected by underline are not significantly different from each other at 0.05.

Table 6. Experiment II: Analysis of Variance Summary Table; TTS Data Exposure Level

Source	Mean Squares	Degrees of Freedom	F Ratio	Significance Level
Between Subjects				
Error	63.294	19		
Within Subjects				
Exposure Level	259.722	5	36.811	<0.001
Error	7.056	100		

increased, there was a significant increase in the TTS score. A Newman-Keuls follow-up test was performed on the main effect of exposure level. The results of the follow-up test are shown in Table 7 using Duncan's underlining technique. The lowest exposure level that resulted in a significant TTS was 95 dB. This is a higher level than that which induced a significant LDI shift.

Based on the information obtained in the case history, the subjects were divided into two groups. Seven subjects were classified as noise exposed and thirteen subjects were classified as non-noise-exposed. A subject was classified as noise-exposed if a yes answer was given to questions 4, 15 or 16 of the questionnaire found in Appendix A. Also, if the subject had a second job or hobby that involved high level noise exposure (questions 17 and 18), he/she was classified as noise-exposed. The LDI data obtained on the noise-exposed subjects and the non-noise-exposed subjects were evaluated in an Analysis of Variance. This was a two-factor design with two levels of subject type (noise-exposed and non-noise-exposed) and six levels of exposure level factor. The data entered in each cell of this analysis were LDI information. The results of this analysis are summarized in Table 8.

The small F ratio for the subject type factor indicates that there was not a significant difference across the two levels of noise exposures in the LDI obtained between the noise-exposed subjects and the non-noise-exposed subjects. A similar Analysis of Variance was performed on the TTS data obtained on the two groups of subjects. The results of this analysis are summarized in Table 9. The subject factor had a nonsignificant F ratio, indicating no significant difference

Table 7. Mean TTS Following 2000 Hz Exposure

	Exposure Level (dB)					
	80	85	90	95	100	105
*Mean TTS Scores	2.619	3.333	4.047	5.476	8.095	11.904

*Values connected by underline are not significantly different from each other at 0.05.

Table 8. Experiment II: Analysis of Variance Summary Table; LDI Data with Factors of Subject Type (N2) and Exposure Level (N6)

Source	Mean Squares	Degrees of Freedom	F Ratio	Significance Level
Between Subjects				
Subject Type	5248.016	1	1.955	0.178 (Exact Level)
Error	2685.025	19		
Within Subjects				
Exposure Level	2776.508	5	10.627	<0.001
Interaction	272.778	5	1.044	0.397 (Exact Level)
Error	261.166	95		

Table 9. Experiment II: Analysis of Variance Summary Table; TTS Data with Factors of Subject Type (N2) and Exposure Level (N6)

Source	Mean Squares	Degrees of Freedom	F Ratio	Significance Level
Between Subjects				
Subject Type	25.397	1	0.389	0.540 (Exact Level)
Error	65.288	19		
Within Subjects				
Exposure Level	259.722	5	37.821	<0.001
Interaction	10.635	5	1.549	0.182 (Exact Level)
Error	6.867	95		

between the performance of the two types of subjects (noise-exposed and non-noise-exposed) when the TTS data were compared across the six sound exposure levels.

Conclusions

The results reported above show growth in TTS, in LD shift at each increment magitude and in LDI as the exposure tone was increased in level. Specifically, the mean LDI (across the 20 subjects) showed a significant shift (0.05 level) from the pre-test following the five-minute exposure at 85 dB. The LD data averaged across the increment magnitudes showed a significant change (0.05 level) following the 90 dB five-minute noise exposure. The TTS data did not show a significant (0.05 level) change from the pre-test data until a five-minute exposure of 95 dB was reached.

There was no significant different between the noise-exposed subjects and non-noise-exposed subjects on either the TTS or LDI calculated at the various exposure levels. The results of no difference between the noise-exposed and non-noise-exposed subjects could lead to at least two different hypotheses. The first is that there is no difference in the performance of these two groups on the LD test or TTS test. The second conclusion is that the case history information did not accurately reflect the subjects' previous noise exposure and thus the subjects were not properly classified as being noise-exposed or non-noise-exposed. The case history information was based on each person's subjective evaluation of his or her past noise

exposure and each subject might have a different criterion for what constitutes a noisy situation.

Several procedural problems were evident in this experiment. These problems include measurement difficulties during the period immediately following the exposure sound. That is, it was difficult to obtain accurate LD measurements during the first 30 seconds after the sound exposures of 95 dB and higher. Some of the subjects complained that tinnitus immediately following the exposure made it difficult for them to concentrate on the task. At these high levels, some of the subjects initially experienced some TTS and consequently, the sensation level of the LD test was considerably less than in pre-exposure testing. Because of this combination of problems, taking the LD measure should be delayed until some specified time after the noise exposure.

A significant LDI occurred following the five-minute exposure at 85 dB SPL. This suggests that it may be possible to work at lower exposure tone levels than 105 dB to obtain the LDI change effect. This test modification would cut down on the noise hazard and discomfort experienced by exceptionally sensitive subjects.

At one-day post-exposure, all the subjects' LD scores had returned to within ± two responses (out of ten) of the pre-exposure scores. All subjects' threshold measures had also returned to ±5 dB of the pre-exposure values. These results indicate that the threshold shifts and LD shifts were temporary responses to high level noise exposures.

Based on the information obtained in Experiment II, it was concluded that:

1) The LD measure should be obtained after a 30-second wait following noise exposure.

2) The noise exposure level should not exceed 100 dB.

CHAPTER IV

EXPERIMENT III: EVALUATION OF HOW SPECTRUM OF NOISE AFFECTS AN LD GROWTH TEST

Objectives

A review of the current literature and the results of the pilot studies reported in Chapters II and III suggest that measurable changes in loudness discrimination may develop following exposure to high level noise. The changes in loudness discrimination may develop in the absence of a permanent threshold shift and may characterize a temporary noise-induced hearing impairment that is different from a threshold shift.

Features of a test procedure of practical value in hearing conservation programs are that it must require little testing time, be easy to administer, require minimal instrumentation, and be reliable, sensitive and valid. The LD test described in Experiment II will be referred to as the LD growth test. This LD growth test appears to be a test paradigm that will meet the requirements in the areas of testing time, ease of administration, and instrumentation. Further research should be done to insure that the LD growth procedure is a sensitive and reliable measure of the difference limen shift. Experiment III will evaluate parameters that may affect the sensitivity of the LD procedure as well as assess the reliability of the measure. The specific parameters are:

a) The effects of the spectral content of the noise exposure on the sensitivity of the LD growth measure.

b) The reliability of the LD function.

c) The effects of the spectral content of the sound exposure on TTS measure.

d) The correlation between the LD growth function and the TTS function.

A parameter of the LD growth test that may affect the sensitivity of the measure is the type (spectral content) of exposure sound used. The effects of different exposure sounds with different spectral content should be investigated in a LD test. For this experiment, the types of exposure sounds were broad band noise and 2000 Hz pure tone. These two sounds are extremely different in spectral content, so that if the spectral content of the exposure sound affects the LDS, there should be a difference between the LDS measured with the broad band noise and the pure tone.

The reliability of the LD function should be evaluated. A test that employs an LD measure cannot be reliable if the measure itself is not repeatable.

The effect of different levels of sound exposure, with different spectral content, on the growth of TTS measured immediately following cessation of brief sound exposures was examined in this project, using pure tone and a broad band noise. It can be assumed that if the spectral content of the exposure sound affects the growth of TTS, the use of sounds with very different spectra should demonstrate this.

The shifts in the loudness function and in thresholds following high level sound exposure may be manifestations of two different auditory changes that result from noise exposure. If the correlation between the LDI growth and TTS growth test is low, this hypothesis of

independent auditory change would be substantiated and would give credence to the use of these two tests as a battery for the diagnosis of noise-susceptible individuals.

<u>Hypotheses</u>

In view of the above, this third experiment was done to test the following hypotheses:

a) There is a significant difference in the LDS and in the LDI:

   1) as the exposure sound is increased in intensity,

   2) as the size of the LD increment magnitude is increased, and

   3) for broad band noise vs. pure tone.

b) There is a significant difference in the TTS measure:

   1) as the exposure sound is increased in intensity, and

   2) for broad band noise vs. pure tone.

c) In LDS and in LDI, there is an interaction between increment magnitude and exposure level.

d) There is a nonsignificant correlation between the LDI and TTS.

<u>Subjects</u>

Twelve male and eighteen female subjects between the ages of 17 and 30 participated in this experiment. Twenty were obtained from the pool of trained listeners used in audiological experiments in the Environmental Acoustics Laboratory. Ten of the subjects were volunteers from the State College, PA area and were considered untrained. These

untrained subjects were familiarized with the task prior to the actual collection of data. All subjects were found to have thresholds within normal limits (<20 dB HL) from 500 Hz through 8000 Hz. The data in this experiment were collected on one ear of each subject. The right ear was used for all subjects unless the left ear showed significantly better thresholds. The same 30 subjects were used in both Procedure A and Procedure B of this experiment.

Equipment

The equipment used for both Procedure A and Procedure B of this experiment is diagrammed in Figure 1.

The output of a pink noise generator was fed into an auxiliary input of a Maico MA-18 clinical audiometer. Pink noise was selected for use as the broad band noise in this experiment because it is similar to noises found in industrial settings. This pink noise provided a noise source that had equal energy per octave band from 150 Hz through 10,000 Hz. One output channel of the audiometer was fed through the LD test unit and 16 dB attenuator pad to a TDH-39 earphone with an MX-41/AR cushion located in the double-wall audiometric subject test room. The tester, noise generator, audiometer, and attenuator pad were located in a double-walled control room. A talk-back system was installed to enable the tester to hear the subject in the test room. The LD test unit, as well as the attenuation pad, could be selectively bypassed.

The LD test unit was designed to pass tones from the audiometer to the headphones at whatever level is set on the audiometer and randomly

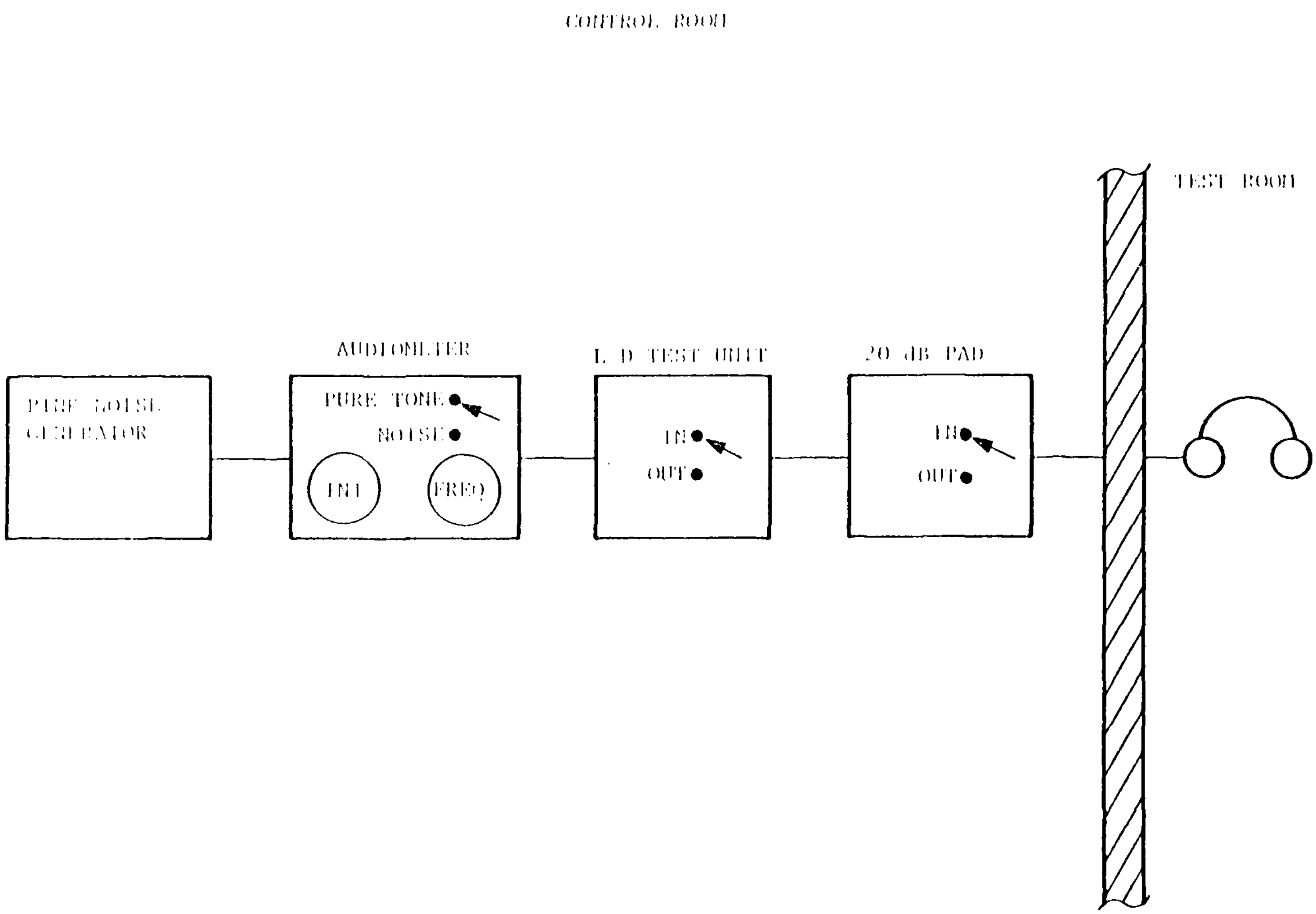

FIG. 1 EQUIPMENT FOR EXPERIMENT III

(once every 2-1/2 to 5 seconds) produce a brief increment in the level of the continuous tone delivered to the earphones. Each increment has a duration of 200 msec. with 50 msec. rise and fall times. The magnitudes of the increments could be selectively varied by the tester. The LD unit could be set automatically to produce increments of 3.0, 2.0, 1.5, 0.8, 0.6, 0.4, 0.2, or 0.1 dB magnitude. For example, when the dial was set at 3 dB, a 50 dB HL tone was raised periodically to 53 dB for approximately 200 msec. These increment magnitudes were separated by 15 random time intervals between 2.5 and 5 seconds. These time intervals are listed in Table 10.

The Maico MA-18 clinical audiometer was calibrated to the ANSI (1969) calibration standard for normal hearing.

To obtain pure tone air conduction thresholds, the tone and frequency selector was set on the audiometer with the output selector on tone, the LD unit was bypassed, and the attenuator pad was put into the system. This audiometer, coupled with the attenuation pad, provided for attenuation of pure tone thresholds below all of the subjects' thresholds. Thus, an ascending method could be used to obtain thresholds.

For the pink noise exposure, the audiometer output selector was switched to tape, and the LD unit and attenuator pad were bypassed. The exposure level was set using the audiometer attenuator and VU meter. The pink noise was calibrated with a B & K 2203 sound level meter and artificial ear such that 70 dB on the audiometer attenuator dial read 80 dB(A) SPL on the sound level meter with the VU meter set

Table 10. LD Test Unit Time Intervals in Seconds

2.50, 2.68, 2.86, 3.04, 3.21, 3.39, 3.57,
3.93, 4.12, 4.28, 4.46, 4.64, 4.82, 5.00

to -7 dB. The hearing level attenuator dial was linear and thus all exposure levels were set respective to the above reference values.

The system was set up in a similar manner for the pure tone exposure. The continuous tone was selected on the audiometer at 2000 Hz. The DL unit and attenuator pad were bypassed, and the signal was fed directly to the earphones. The exposure level was set using the attenuator dial of the audiometer to adjust the output to 80, 85, 90, 95, or 100 dB SPL measured with a B & K 2203 sound level meter and artificial ear.

To obtain an LD function, a continuous 4000 Hz tone was passed from the audiometer through the DL unit and attenuator pad. The hearing level dial was set at 66 dB HL so that a 50 dB HL tone was produced by the earphones. The LD increment magnitude was selected as being either 3.0, 2.0, 1.5, 0.8, 0.6, 0.4, 0.2, or 0.1 dB. This resulted in a 50 dB HL 4,000 Hz continuous tone that increased a selected magnitude at random time intervals between 2.5 and 5 seconds.

Procedure A

In this part of the experiment, data were collected on the effects of using a 2000 Hz pure tone exposure in an LD growth test procedure. Information about the growth of TTS following brief exposure to several sound pressure levels of a 2000 Hz tone was also obtained in this section. These data, along with the data collected in the next section, were used to test the hypotheses stated earlier.

Initially, threshold measures were obtained, at 250, 500, 1000, 2000, 4000, and 8000 Hz, on the 30 subjects. All thresholds were

obtained using 5 dB steps and an ascending approach. The criterion for the threshold measure was the least sound which elicited a positive response two out of three times.

Each subject's baseline LD function was measured using the revised test procedure based upon conclusions developed in earlier studies. The LD tests were performed using a 4000 Hz tone at 50 dB HL at 3.0, 2.0, 1.5, 1.0, 0.8, 0.6, 0.4, 0.2, and 0.1 dB increment magnitudes. The signal increments were presented at random time intervals between 2.5 and 5 seconds.

The LD test began by presenting ten practice items with increments of 3.0 dB to familiarize the subject with the task. The increment magnitude was then changed to 2.0 dB and three practice increments were presented. The actual test period began with the fourth presentation at the 2.0 dB increment magnitude and an additional nine items were presented at this magnitude. In Experiment II, up to five practice items were used before the actual test; however, it was felt that three practice items were adequate for familiarizing the subject at each increment. The number of items correctly identified out of the ten test presentations was recorded as the subject's response at that increment magnitude. The LD test proceeded through each of the increment magnitudes (1.5, 1.0, 0.8, 0.6, 0.4, 0.2, 0.1), in descending order, until the subject was unable to identify correctly any of the ten test items presented at an increment level. At each increment magnitude three practice presentations preceded the ten-item test period. The threshold measure and LD test at 4000 Hz made up the pre-exposure test sequence.

Following the pre-exposure test, the subjects were exposed to a 2000 Hz tone at 75 dB SPL for five minutes in the test ear. The subject's threshold at 4000 Hz was measured within the first 30-second period immediately following the exposure (TTS), and the LD function was measured at 50 dB HL and 4000 Hz. This post-exposure LD test began with the smallest increment magnitude at which the subject identified all the items presented in the LD pre-exposure test; otherwise, the same test procedure, increment magnitude and sequence were used as in the pre-test. This LD measure followed the threshold measure at 30 seconds post-exposure and was completed at approximately 3-1/2 minutes post-exposure.

Following these measurements, each subject was exposed to a 2000 Hz tone at 80 dB SPL for five minutes after which the same threshold TTS (30 sec.) and LD, post-exposure test sequence was administered. This procedure was repeated five times, with an increase in the exposure tone of 5 dB for each trial, until an exposure of 100 dB was reached or until a 20 dB TTS was found after cessation of the exposure. The testing for each subject was conducted according to the format shown in Table 11.

Procedure B

In this section, data were collected on the LD growth test and TTS following brief exposure to different levels of a broad band noise. The same 30 subjects used in Procedure A were used in this data collection procedure. The experiment was conducted in a manner identical to that described in Procedure A with the exception that a broad band pink

Table 11. Test Format for Procedure A

Exposure	Test Sequence
2K Hz Tone for 5 min at 75 dB /	threshold at 4K Hz and LD at 4K Hz
2K Hz Tone for 5 min at 80 dB /	threshold at 4K Hz and LD at 4K Hz
2K Hz Tone for 5 min at 85 dB /	threshold at 4K Hz and LD at 4K Hz
2K Hz Tone for 5 min at 90 dB /	threshold at 4K Hz and LD at 4K Hz
2K Hz Tone for 5 min at 95 dB /	threshold at 4K Hz and LD at 4K Hz
2K Hz Tone for 5 min at 100 dB /	threshold at 4K Hz and LD at 4K Hz

noise was delivered to the test ear of the subject instead of a 2000 Hz pure tone. This pink noise had equal energy per percentage bandwidth from 20 Hz through 15,000 Hz. This pink noise will be referred to as just broad band noise throughout the rest of this study.

In summary, Procedure B began by obtaining a threshold and an LD function at 4000 Hz on all 30 subjects. This pre-test procedure was identical to that described in Procedure A. The subjects were then exposed to a broad band noise at 75 dB(A) for five minutes. This exposure was followed by a threshold and an LD function obtained using a sequence and procedure identical to that used in Procedure A. As in Procedure A, this exposure, post-exposure test sequence was repeated five times, with an increase in the exposure sound of 5 dB(A) for each trial, until either an exposure of 100 dB(A) or a 20 dB TTS is reached. Thus, the test was conducted according to the format shown in Table 12.

All subjects completed Procedure A over a period of about four weeks. As each subject completed Procedure A, he or she was scheduled to return for Procedure B. The minimum time between Procedures A and B was four weeks for a subject; all were given Procedure B within 12 weeks of having Procedure A.

Experiment III LDS Results

The mean data averaged across the 30 subjects are shown in Table 13. This table includes the mean data for each increment magnitude and each exposure level for both Procedure A and Procedure B.

A three-way analysis of variance was performed to test the effects of the test parameters in this experiment on the LD function. The

Table 12. Test Format for Procedure B

Exposure	Test Sequence
Broad band noise exposure for 5 min @ 75 dBA	threshold @ 4000 Hz & LD @ 4000 Hz
Broad band noise exposure for 5 min @ 80 dBA	threshold @ 4000 Hz & LD @ 4000 Hz
Broad band noise exposure for 5 min @ 85 dBA	threshold @ 4000 Hz & LD @ 4000 Hz
Broad band noise exposure for 5 min @ 90 dBA	threshold @ 4000 Hz & LD @ 4000 Hz
Broad band noise exposure for 5 min @ 95 dBA	threshold @ 4000 Hz & LD @ 4000 Hz
Broad band noise exposure for 5 min @ 100 dBA	threshold @ 4000 Hz & LD @ 4000 Hz

Table 13. Summary Data for Procedures A and B

Procedure A (2000 Hz Exposure)

Exposure Level	Increment Magnitude							
	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Pre								
Mean	0	.27	.93	3.46	5.6	8.40	9.70	10.0
SD	0	.90	2.15	3.24	3.19	1.95	.59	0
75 dB								
Mean	0	.37	1.47	3.70	6.56	8.83	9.80	10.0
SD	0	1.03	2.56	3.15	2.47	1.48	.43	0
80 dB								
Mean	0	.10	1.60	4.27	7.00	8.63	9.90	10.0
SD	0	.40	2.34	3.29	2.62	1.82	.30	0
85 dB								
Mean	0	.13	1.80	4.60	6.75	8.68	9.80	10.0
SD	0	.43	2.49	2.94	2.76	1.92	.80	0
90 dB								
Mean	.06	.30	2.50	5.20	7.40	8.93	9.80	10.0
SD	.25	.74	2.93	2.89	2.64	1.76	.50	0
95 dB								
Mean	.23	.40	2.41	5.36	7.70	9.23	9.76	10.0
SD	.80	.85	2.59	3.31	2.32	1.16	.42	0
100 dB								
Mean	.10	.57	2.92	5.75	7.44	9.21	9.80	10.0
SD	.14	1.13	2.73	3.51	2.97	1.44	.50	0

Table 13. Summary Data for Procedures A and B (Cont'd)

Procedure B (Broad Band Noise Exposure)

Exposure Level	Increment Magnitude							
	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Pre								
Mean	0	.23	1.23	3.62	6.38	9.00	9.17	10.0
SD	0	.82	2.23	3.06	2.71	1.50	2.29	0
75 dB								
Mean	0	.30	1.35	4.17	6.47	8.73	9.57	10.0
SD	0	1.05	2.90	3.46	2.76	1.87	1.68	0
80 dB								
Mean	.03	.50	2.27	4.60	6.73	8.53	9.90	10.0
SD	.21	.97	3.06	3.40	3.17	2.16	.30	0
85 dB								
Mean	.33	.80	2.77	5.00	6.80	8.67	9.17	10.0
SD	.88	1.73	3.25	3.29	2.87	2.15	2.40	0
90 dB								
Mean	.06	.40	2.43	5.07	7.27	8.70	9.70	9.94
SD	.25	.77	2.69	3.12	2.83	1.99	.99	.30
95 dB								
Mean	0	.67	2.90	5.50	7.27	8.93	9.80	10.0
SD	0	1.15	2.69	3.40	2.98	1.81	.60	0
100 dB								
Mean	.03	.51	3.10	6.00	7.69	8.93	9.67	9.94
SD	.21	.83	2.84	3.44	3.21	2.28	.86	.30

design of this analysis was a three-factor repeated measures analysis of variance with eight levels of the increment magnitudes factor, six levels of the exposure level factor, and two levels of the exposure type factor (increment X exposure level X exposure type). The data entered for each of the 30 subjects were LD shift scores (LDS). The LDS data were calculated by subtracting each subject's pre-exposure data at each increment magnitude from the post-exposure data collected at each respective increment magnitude. LDS scores were calculated for every level of exposure (75 dB through 100 dB) for the data collection in both Procedures A and B of this experiment. Thus, an LDS score at each increment magnitude for each of the exposure levels was calculated for both types of sound exposure.

The results of this three-way Analysis of Variance are summarized in Table 14.

There is a significant (ELxIM) or exposure level by increment magnitude interaction. This interaction was a result of the way the LD growth test was conducted. That is, at the large increment magnitudes the subjects identified most of the test items in the pre-test as well as in the post-exposure test. Because of ceiling effects the subjects demonstrated small LD shifts.

For example, a subject may have identified nine items on the pre-test and all of the items on the post-exposure test. This resulted in a small LDS because only ten items were presented. For the increment magnitudes of 0.4 dB through 1.0 dB, some of the subjects' LDS increased as the exposure sound increased. At the increment magnitudes of 0.2 dB and 0.1 dB, many of the subjects missed the items in the

Table 14. Analysis of Variance Summary Table for Experiment III; LDS Data with Factors of Exposure Level (N6), Exposure Type (N2), and Increment Magnitude (N8)

Source	Mean Squares	Degrees of Freedom	F Ratio	Significance Level
Between Subjects				
Error	38.103	29		
Within Subjects				
Exposure Type (ET)	60.089	1	6.276	0.018 (Exact Level)
Error	9.575	29		
Exposure Level (EL)	27.401	5	14.759	<0.001
Error	1.857	145		
(ETxEL) Interaction	3.711	5	2.319	0.046 (Exact Level)
Error	1.600	145		
Increment Magnitude (IM)	141.080	7	12.802	<0.001
Error	11.020	203		
(ETxIM) Interaction	7.288	7	1.834	0.082 (Exact Level)
Error	3.973	203		
(ELxIM) Interaction	4.477	35	4.984	<0.001
Error	0.989	1015		
ETx ELxIM Interaction	0.510	35	0.626	0.957 (Exact Level)
Error	0.814	1015		

pre-test as well as in the post-exposure test. Thus, the subjects showed small LDS scores for the large increment magnitudes because of ceiling effects, large LD shifts for the mid range increments and small LDS for the small increment magnitudes as the exposure sound was increased. This resulted in an exposure level by increment magnitude interaction. There was also a significant ETxEL (exposure type by exposure level) interaction. This interaction can be better understood when the main means of exposure type are examined at the various exposure levels. Table 15 lists these mean LDS scores based on 240 observations.

Note the mean LDS for the broad band noise increased from the 75 dB exposure to the 85 dB exposure. At 90 dB exposure, the mean LDS score decreased and then increased again through the 100 dB exposure level. The mean LDS score obtained using a 2000 Hz pure-tone exposure sound, however, gradually increased from the 75 dB exposure through the 100 dB exposure. The variation in the LDS scores across the exposure levels accounts for the ETxEL interaction. When a Newman-Keuls follow-up test of significant different was performed on these data, it was found that there was no significant difference between mean LDS scores obtained at the 85, 90, and 95 dB exposure levels for the broad band noise. Thus, while there is a significant ETxEL interaction the importance of this interaction is questionable.

There was a significant F ratio for each of the exposure type (ET), exposure level (EL), and increment magnitude (IM) factors. The significant F ratio for increment magnitude (IM) indicates that there was

Table 15. Mean LDS Scores Averaged Across Increment Magnitude

Exposure Type	Exposure Level (dB)					
	75	80	85	90	95	100
Noise	3.4	5.5	8.0	6.2	8.5	9.7
2000 Hz tone	0.9	1.9	2.0	5.1	6.5	7.7

a significant increase in the number of items identified as the increment magnitude was increased. Specifically, subjects identified more of the large increment magnitudes than the small increment magnitudes.

The significant F ratio for type of exposure (ET) indicates that there was a significant difference in the LDS score. Examination of the mean values collapsed across increment magnitudes and exposure levels showed that the LDS was significantly greater when the broad band exposure was used. Since the broad band noise exposure produced larger changes in the LDS sources, it may be considered the more sensitive stimulus for measuring LDS growth.

The large F ratio for the exposure level (EL) factor indicates that there was a significant difference in the LDS scores as the level of noise exposure was changed. The LDS scores increased as the exposure sound was increased. A Newman-Keuls follow-up test was performed on mean LDS scores to examine the main effects of exposure level separately for each type of sound exposure. The results are shown in the Table 16 employing Duncan's underlining technique to identify nonsignificant pairs of means.

In Table 16, the mean LDS scores were averaged across the 30 subjects and across the eight increment magnitudes. The results of the follow-up test indicate that the lowest exposure level which resulted in a significant shift in the mean LDS scores for the broad band noise exposure was 85 dB SPL. As discussed previously, the mean LDS scores obtained following the broad band noise exposure increased from the 75 dB SPL through 85 dB SPL, decreased at 90 dB SPL, and increased again until a 100 dB SPL noise is reached.

Table 16. Follow-Up Test on Mean LDS Data

	Exposure Level (dB)					
	75	80	85	90	95	100
*Noise	3.4	5.5	6.2	8.0	8.5	9.7

	Exposure Level (dB)					
	75	80	85	90	95	100
*2000 Hz	0.9	1.9	2.0	5.1	6.5	7.7

*Values underlined are not significantly different at 0.05.

When the main effect Exposure Level was examined for the 2000 Hz exposure, a significant shift in mean LDS scores occurred following the 90 dB SPL exposure. With this LDS data obtained following the pure tone exposure, there was a consistent trend of increasing mean LDS scores with an increase in exposure level.

Experiment III LDI Results

The mean LDI data averaged across the 30 subjects is shown in Table 17. This table includes the mean data for each exposure level for both Procedure A and Procedure B.

A two-way analysis of variance was performed using LDI data. The LDI scores were calculated for each exposure spectrum and dB level by selecting the largest LDS score obtained on each subject across exposure levels (i.e., 80, 85, 90, 95, or 100 dB). The LDI scores were entered into the respective cells of an Analysis of Variance with repeated measures with two levels of the exposure type factor and six levels of the exposure level factor. The results of this analysis are summarized in Table 18. Note that there is a significant interaction. The exposure type by exposure level interaction is the result of the same trend that was observed with the LDS data. That is, the main effects for the mean LDI data (averaged over the 30 subjects) for the broad band noise show an increase in the LDI as the noise was increased from 75 dB to 85 dB. The mean LDI scores then decreased at 90 dB exposure and increased through the 100 dB exposure. The mean LDI scores for the 2000 Hz pure tone exposure continued to increase from the 75 dB exposure through the 100 dB exposure. When the mean LDI

Table 17. Experiment III: Mean LDI Data (Across Subjects) for Procedure A (2000 Hz) and Procedure B (Noise)

	Exposure Level (dB)					
	75	80	85	90	95	100
Noise	1.37	2.40	3.45	2.50	3.33	3.77
2000 Hz	0.60	0.40	0.97	1.77	2.58	2.83

Table 18. Experiment III: Analysis of Variance Summary Table; LDI Data by Exposure Type (N2) and Exposure Level (N6)

Source	Mean Squares	Degrees of Freedom	F Ratio	Significance Level
Between Subjects				
Error	58.528	29		
Within Subjects				
Exposure Type (ET)	149.511	1	10.419	0.003 (Exact Level)
Error	14.350	29		
Exposure Level (EL)	46.364	5	12.080	<0.001
Error	3.838	145		
Interaction (ETxEL)	8.758	5	2.311	0.047 (Exact Level)
Error	3.790	145		

scores for the broad band noise were compared with a Newman-Keuls follow-up test, the decrease in the mean LDI scores at 90 dB was found to be nonsignificant.

The significant F ratio for the type of exposure factor indicates that there was a significant difference between the scores obtained using the two types of exposure sound; the shift in the LDI scores following the broad band noise exposure was larger following the 2000 Hz exposure.

The F ratio for the exposure level factor indicates that there was a significant difference across the exposure level factor. The main effect of exposure level was examined for the two difference exposure sounds separately using a Newman-Keuls test. The results of this analysis are shown in Table 19 employing a Duncan's underlining technique.

The results indicate that, for the broad band noise exposure, there was a significant shift in the LDI data following the 85 dB exposure. The follow-up tests on the 2000 Hz exposure, however, did not show a significant shift in the LDI until the 95 dB exposure was reached. Thus, the LDI data do not show the same point of significant change as the follow-up test performed with the LDS data. In general, the significant shifts occurred at a lower sound level when the broad band noise exposure was used in the LD growth test.

Experiment III TTS Results

The next section of the data analysis examined the TTS growth as a function of exposure level and exposure spectrum. To obtain the TTS

Table 19. Follow-Up Test on Mean LDI Data

	Exposure Levels (dB)					
	75	80	85	90	95	100
2000 Hz	0.400	0.600	0.967	1.767	2.533	2.833

	Exposure Levels (dB)					
	75	80	90	85	95	100
Noise	1.37	2.40	2.50	3.33	3.45	3.77

data the pre-exposure thresholds for each subject were subtracted from his/her post-exposure thresholds for each exposure level. For each subject, six TTS values were calculated for Procedure A, and six TTS values were calculated for Procedure B. The TTS values were entered into the cells of a two-way Analysis of Variance with a repeated measures design with six levels of the exposure level factor and two levels of the exposure type. The results of this analysis are summarized in Table 20.

The F ratio for exposure type was nonsignificant, indicating no significant difference between TTS following the broad band noise exposure and TTS following 2000 Hz pure tone exposure. This result is contrary to the results obtained with the LD information which demonstrated a difference between the types of exposure.

The F ratio for the exposure level factor was large, and the main effect factor was evaluated using a Newman-Keuls follow-up test. The results of this analysis are shown in Table 21, using Duncan's under lining technique to connect nonsignificant pairs of means. The lowest exposure level that showed a significant shift was 95 dB SPL.

Because the broad band noise exposures resulted in the largest LDS scores (see Table 15), the main effects of these exposures were examined using the TTS measurements. This analysis was also done using a Newman-Keuls follow-up test; the results are displayed in Table 22. These results indicate that the lowest significant shift in TTS scores took place following a broad band exposure of 80 dB.

Table 20. Experiment III: Analysis of Variance Summary Table; TTS Data with Factor of Exposure Level (N6) and Exposure Type (N2)

Source	Mean Squares	Degrees of Freedom	F Ratio	Significance Level
Between Subjects				
Error	82.972	29		
Within Subjects				
Exposure Type	0.0694	1	0.001	0.972 (Exact Level)
Error	56.535	29		
Exposure Level	629.903	5	75.169	<0.001
Error	8.380	145		
Interaction	16.569	5	2.556	<0.030
Error	6.483	145		

Table 21. Follow-up Test on Mean TTS Data in dB
Pooled Across Exposure Type

	Exposure Level (dB)					
	75	80	85	90	95	100
Mean Shift in dB	2.083	3.416	4.833	5.667	7.833	11.083

Table 22. Follow-Up Test on Mean TTS Values for Broad Band Noise

	Exposure Levels (dB)					
	75	80	85	90	95	100
Mean Shift in dB	2.000	3.666	5.333	6.167	7.333	10.333

Experiment III Correlation Results

The correlations between the TTS and LDI data at each exposure level for each type of exposure sound are summarized in Table 23. Pearson Product Moment Correlations across the 30 subjects were calculated for these data for the two types of sound separately. The only correlation between the TTS and LDI that was significant (.05) was for the 100 dB Lp 2000 Hz exposure. The low product moment correlations can be the result of either a curvilinear relationship, or no relationship between the LDI and TTS data. Therefore, scatterplots were made. The scatterplots of the TTS and LDI data for each exposure type and at every exposure level are shown in Appendix B. None of these scatterplots show a curvilinear relationship or a distinguishable pattern. It is concluded, therefore, that the low correlation between the LDI and TTS data reflects a random relationship between these two types of data. Even the significant r for the 100 dB exposure sound is, although significantly different from zero, low and of little predictive value.

Experiment III Reliability Measures

Several measures of reliability were made on the LDS data. The raw score LDS data were examined to determine if there were any significant differences in the LD function collected in the pre-test for Procedure A and Procedure B by comparing the data collected in Procedures A and B for each subject. This comparison was made in the form of two two-factor repeated measures, eight levels of the increment magnitude factor, and two levels of the test condition factor (Procedures A and B).

Table 23. Correlations for LDI and TTS Means
Pooled Across Subjects (N30)

Exposure Level in dB SPL	2000 Hz	Broad Band Noise
75	0.042	0.275
80	0.103	0.024
85	0.205	0.085
90	0.214	0.081
95	0.017	0.233
100	*0.395	0.139

*Significant at 0.05.

The raw score data for each subject were entered into the cells of the analysis for every increment magnitude (0.1 through 2.0 dB) in the pre-test of Procedure A and the pre-test of Procedure B. The results of this analysis are summarized in Table 24.

There was no significant interaction between the test condition and increment magnitudes and thus the main effects were tested. The F ratio for the test condition was nonsignificant and it can be included that this factor was not a significant contributor to the systematic variance in the data. The F ratio for the increment magnitude factor was highly significant and the variance in the raw data can be accounted for in terms of the change in increment magnitude. Thus, there was no significant difference in the subject performance on the two pretests at the respective increment magnitudes.

The reliability of LD growth test was also calculated by Pearson Product Moment Correlations in a test-retest paradigm. A correlation coefficient was obtained for the pre-test data collected using Procedure A and Procedure B at each increment magnitude. These correlations are listed in Table 25.

At the largest (2.0) and smallest (0.1) increment magnitudes, a meaningful correlation could not be obtained because all subjects obtained identical scores of 0 and 10 respectively. The correlations obtained at the increment magnitudes of 0.2 dB through 1.5 dB are significant at a 0.05 level, indicating adequate reliability for the LD growth measure test.

Table 24. Experiment III: Analysis of Variance Summary Table; Pre-Test Data with Factors of Test Condition (N2) and Increment Magnitude (N8)

Source	Mean Squares	Degrees of Freedom	F Ratio	Significance Level
Between Subjects				
Error	19.563	29		
Within Subjects				
Test Condition (TC)	5.419	1	1.712	0.201 (Exact Level)
Error	3.164	29		
Increment Magnitude (IM)	1084.469	7	306.919	<0.001
Error	3.533	203		
Interaction	1.143	7	1.048	0.399 (Exact Level)
Error	1.090	203		

Table 25. Pearson Product Moment Correlations Between Pre-Test Data of Procedures A and B (N30)

Increment Magnitudes (dB)							
0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
*	0.56	0.89	0.51	0.66	0.42	0.60	*

*All scores were identical because of ceiling effect and no meaningful correlation could be obtained; all other r values significant at 0.05.

A reliability estimate was calculated to determine how much variance can be expected when the LDI test is used. The pre-exposure LDS was obtained for each subject by subtracting, at each respective increment magnitude, the LD score obtained on the pre-test of Procedure A from the LD score obtained on the pre-test of Procedure B. Even though Procedures A and B used different types of noise for exposure, the pre-test data were collected prior to exposure and therefore could be compared. Table 26 lists the LDS pre-exposure data means and standard deviations of the 30 subjects at each respective increment magnitude.

Note that the largest standard deviation occurred at the 0.6 dB increment magnitude. Using this largest standard deviation as a conservative estimate of variability, it can be concluded that an individual's LDI must change by more than four (i.e., two standard deviations) in order to be 95% confident that the LDS is due to some phenomenon other than individual variation in the test, pre-test situation.

Summary of Experiment III Results

Based on the results obtained in this study, the following general conclusions can be made about these three measures of hearing change:

For the LD function of increment magnitudes 1.5 dB and higher, the subjects could detect almost all test items before and after the noise exposure. The mean pre-exposure LD's (across the 30 subjects) for these increments were 97.3% and 100% for the 1.5 dB and 2.0 dB increments respectively. Due to ceiling effect, little if any change could be observed at these increment magnitudes; therefore, the

Table 26. Pre-Exposure LDS Means and Standard Deviations

	Increment Magnitude (dB)							
	0.1	0.2	0.4	0.6	0.8	1.0	1.5	2.0
Mean	0	0.03	0.30	0.10	0.47	0.50	0.03	0
SD	0	0.81	1.06	2.2	2.1	1.81	0.49	0

remainder of this discussion on LD scores will center on the increments of 1.0 dB and smaller.

There is a change in hearing at 4000 Hz which can be observed in the LD function and threshold measures following high level sound exposure. That is, the ability to detect small changes in loudness improves and thresholds become worse following exposure to high level sounds. These changes in LD function and threshold generally increase as the exposure sound level increases. The changes observed in the LD function and threshold measures are temporary. (This finding is somewhat contradictory to the study by Bekesy (1960) in which his measure of recruitment persisted for one month. This might be due to the different ways of measuring. The subjects' thresholds and LD functions returned to the pre-exposure values by 24 hours post-exposure in the present study.)

The spectrum of the exposure sound affects the LD function. That is, significant changes in the LDS and LDI scores occur at lower levels when a broad band noise exposure is used than when a 2000 Hz pure tone exposure is used (Tables 16 and 19). Specifically, when a broad band noise exposure is used, a significant shift in the LDS and LDI scores occurred at 85 dB. When a pure tone exposure is used, a significant change in the LDS data does not occur until a 90 dB exposure is reached, and a significant change in the LDI data does not occur until the level is increased to 95 dB. Thus, it appears as though the more sensitive measure of change in the LD growth test is obtained when the LD function is measured after a broad band noise exposure.

Subject thresholds become worse following sound exposure. Contrary to the LD data, however, there is no significant difference between the threshold shift following the broad band noise exposure and the pure tone exposure. Thus, the TTS measure does not reflect the same type of response to spectral changes in the exposure sound as the LDS measure. This may suggest that the TTS and LD growth tests measure different types of temporary hearing changes that result from high level sound exposure. The hearing change that the LD growth test reflects varies with the spectral content of the exposure sound, while the hearing change that the TTS growth test reflects does not change with the spectral content of the sound.

The correlation between TTS and LDS data were obtained on the 30 subjects for both the pure tone exposure data and the broad band noise exposure. The correlations between these two measures were low for both types of exposure. These results suggest that, for a given subject, the TTS growth test data cannot be used to predict accurately his/her LDI growth test results and vice versa. The low correlations between these two measures further suggest that the two tests measure different aspects of the hearing changes that result from exposure to sounds. This conclusion is drawn because 1) there is a low correlation between the TTS and LDI growth measures, and 2) changes in the spectral content of the exposure sound affected these two growth measures differently. Since these tests do not duplicate each other, the efficiency of identifying a noise-induced auditory change should be increased when both tests are employed in a test battery. Only those

subjects who show no significant change in either test can be identified as not demonstrating a noise-induced hearing change. Threshold measures alone are presently employed to identify persons who are susceptible to a noise-induced hearing impairment. Thus persons who demonstrate a noise-induced LD change and no threshold change are undetected as being susceptible to a noise-induced hearing change.

The LDI data were also examined in this experiment for each exposure level. (The LDI is the largest LD shift for each listener regardless of the increment magnitude at which it occurred.) Due to ceiling effects arising out of the baseline LD function, subjects varied greatly in the increment magnitude at which they showed the maximum shift. This phenomenon tended to obscure the LD shift on the statistical analysis. The LDI characterizes the LD shift independently of the baseline function and it is a small value that can be examined quickly. The LDI provides similar information to the LDS scores averaged across the increment magnitudes. Both the LDI and LDS change significantly as the exposure level is increased and they both demonstrate an earlier shift with the broad band than with the pure tone exposure. The LDI gives a single number which is easy to obtain, minimizes the variance introduced by individual differences, accurately reflects the averaged LDS findings and is, in some test paradigms, a more sensitive measure of changes in loudness perception than the LDS scores. It is therefore concluded that the LDI can be used in a clinical test procedure designed to measure LD changes that occur following noise exposure. A clinical test of LD changes may be of use as a test

designed to identify subjects who are abnormally sensitive to noise-induced hearing changes.

The LDS data were also examined for repeatability of test results. The pre-exposure raw scores data for the two procedures were compared in a two-way Analysis of Variance with factors of increment magnitude and test condition (Procedures A and B) and no significant changes were found (Table 24). Thus, the variance in the pre-exposure raw data can be accounted for in terms of the change in increment magnitude only.

The reliability of the LD growth test was obtained more directly by calculating a Pearson Product Moment Correlation on the pre-exposure data for the respective increment magnitudes of Procedures A and B. The results of the analysis indicate that the LD growth test shows high test-retest reliability, with all the correlations significant at a 0.05 level.

An estimate of the reliability of LD measures was also obtained by examining the means and standard deviations of the pre-exposure data. The largest standard deviation of this LDS pre-exposure data can be used as a conservative estimate of the variability that can be expected in an individual LDI score. To be 95% confident that the LD shift is due to some phenomenon other than individual variation in the test retest situation, an individual LDI must change by more than 4%.

Appendix C describes a proposed test procedure that can be employed with the LD test described in Procedure B of Experiment III to obtain data on noise-induced changes in the LD function.

CHAPTER V

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Summary and Conclusions

Case history information obtained from the subjects in Experiment II was used to separate the normal hearing subjects with a previous history of noise exposure. These two groups did not differ in TTS growth and LDI growth experienced following a noise exposure. Thus it can be concluded that there was no difference between TTS growth and LDI growth of normal hearing subjects with and without a previous history of noise exposure. This result may be due to the improper classification of the subjects because of variance in subjective criteria of what constitutes a noisy situation.

The rest of this conclusion section pertains directly to the TTS and LD test results obtained in this project.

It is necessary to implement the following procedures and parameters to obtain an efficient and accurate LD function:

1. The timing intervals between successive presentation of the increment magnitudes should be varied randomly.
2. Increment magnitudes smaller than 0.5 dB should be used to characterize the LD function for all individuals.
3. LD measures for increments that produce larger than the 100% response level and smaller than the 0% response level need not be obtained.

4. The LD function should begin with the 2.0 dB increment magnitude since all subjects could detect all test items at 2.0 dB and higher.

5. LD measures should begin at least 30 seconds after the noise exposure.

The equipment necessary to present randomly timed increment magnitudes of 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5 and 2.0 has been designed and constructed. A test procedure that incorporates the above recommendations has also been designed and implemented in the LD growth test examined in this study.

The Loudness Discrimination Shifts, Loudness Discrimination Index, and temporary threshold shifts following sound exposures were examined in this study. Based on the results obtained in this study, the following general conclusions can be made about these three measures of hearing change.

The LD function shows greater change after a short period of time (e.g., 30 seconds) than immediately following the noise exposure. (As mentioned previously, the LD function obtained immediately may have been affected more by other auditory responses which result from noise exposure. These quickly changing auditory responses which result from noise exposure include large threshold shifts and tinnitus.) The time variance between the LD function obtained in Experiment II and in Procedure A of Experiment III was approximately two minutes. This two-minute difference in measuring the LD function resulted in a 5 db change in the exposure level that elicited a significant LDI.

The spectrum of the exposure sound also affected the LD function. Significant changes in the LDS and LDI scores occurred at lower levels when a broad band noise exposure was used than when a 2000 Hz pure tone exposure was used. Specifically, when a broad band noise exposure was used, a significant shift in the LDS and LDI scores occurred at 85 dB. When a pure tone exposure was used, a significant change in the LDS data did not occur until a 90 dB exposure was reached, and a significant change in the LDI data did not occur until the level was increased to 95 dB.

The TTS growth measure was not affected by the spectrum of the noise exposure. That is, there was no significant difference in the growth of TTS following a pure tone exposure and the growth of TTS following a broad band noise exposure. These results suggest that while both the LD growth and threshold growth measure change temporarily following exposure to high level sound, they respond differently to changes in the spectral content of the exposure.

The correlations between the TTS growth and the LDI growth measures were nonsignificant at all the levels of the broad band noise exposure. Thus it can be concluded that a subject's LDI score cannot be predicted from his/her TTS score.

The test-retest reliability coefficient of the LDS measure was significant at a conservative 0.05 level. Clinically, however, it is necessary to observe a change in the LDI score of four or more before one can be 95% confident that this measure reflects an actual change in test scores.

In summary, the findings obtained in this study suggest that the LD growth test and TTS growth test reflect two different temporary auditory changes that result from noise exposure. This is concluded because 1) there is a low correlation between the TTS and LDI growth measures, and 2) changes in the spectral content of the exposure sound as well as post-exposure time delays affected these two growth measures differently.

Because a subject's response on the LD growth test cannot predict his/her response on the TTS growth test and vice versa, it is necessary to collect data on both types of measures to determine if noise-induced hearing change is experienced. That is, the ability to detect small changes in loudness improves, and thresholds or the ability to detect sounds become worse following exposure to high level sounds. These changes in LD function and threshold increase as the exposure sound level increases. The changes observed in the LD function and threshold measures were temporary. The subject's thresholds and LD functions had returned to the pre-exposure values by 24 hours post-exposure.

The LDI measures reflected findings similar to the LDS scores averaged across the increment magnitudes in that they both increased significantly with increased sound exposure. The LDI gives a single number which is easy to obtain, accurately reflects the averaged LDS findings, and is, in some test paradigms, a more sensitive measure of changes in loudness perception than the LDS scores. It is therefore concluded that the LDI should be used in a clinical test procedure designed to identify subjects who are abnormally sensitive to noise-induced LD changes.

AD-A087 101 PENNSYLVANIA STATE UNIV UNIVERSITY PARK APPLIED RESE--ETC F/G 5/10
EVALUATION OF A LOUDNESS DISCRIMINATION TEST.(U)
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In the different LD tests examined in this study, the exposure level at which significant changes in LDI scores occurred was found to depend upon 1) the time after exposure at which the LD measure was obtained, and 2) the kind of exposure used. Specifically, when the LD function was measured at least 30 seconds after exposure to a 2000 Hz tone (Procedure A of Experiment III), significant changes occurred in the LDS scores at 90 dB. When the LD function was obtained immediately after the noise exposure (Experiment II), LDS scores were significant for exposures of 100 dB. These results indicate that when the post-exposure time is increased, the level at which a significant change in the LD function occurs decreases.

Because of the low correlations between the LD and TTS measures, it is questionable whether one of these types of hearing changes precedes the other as an auditory reaction to noise exposure. Until a single clear-cut predictive tool for the identification of a noise-induced pathology is found, a test battery is desirable which incorporates all tests that measure different auditory changes which can result from noise exposure.

Appendix C describes a proposed test procedure that can be employed with the LD test described in Procedure B of Experiment III to obtain data on noise-induced changes in the LD function. This test procedure appears to be a quick and sensitive measure of noise-induced changes that occur in the loudness discrimination function. This author recommends that this LD growth test procedure, in conjunction with the TTS measures, be used to identify those individuals who experience a noise-induced auditory change.

Suggestions for Further Research

It is believed by this author that several design changes should be implemented if Experiment III of this study was repeated. These changes include alterations in the collection procedure and mode of subject response.

To reduce test order effects within the subject group, half of the subjects should be tested with the broad band noise exposure first and half of the subjects should be tested with the pure tone exposure first. In Experiment III, all 30 subjects were tested first with the pure tone exposure and in the next session with the broad band exposure. If the subjects' ability to detect changes in loudness improved with practice, larger LD shifts would be noted on the second procedure. This was the case.

Another suggestion for the improvement of the experimental design is to have the subjects respond by using a response button. In this study the subjects responded by raising a finger when a change in the loudness of the stimuli was noted. Occasionally a subject would partially raise his/her finger. This response had to be interpreted by the experimenter as a positive or negative response. A button/light response would mandate a yes or no subject response. This would reduce experimental bias.

If the LD growth test is to be used as part of a test battery to identify people who are susceptible to some type of noise-induced auditory change, it must be validated. It is imperative that longitudinal studies of LD functions be conducted to investigate the relationship between the temporary noise-induced changes in the LD function

and permanent noise-induced auditory impairment. This study showed that the temporary noise-induced changes in the LD function did not correlate with TTS measures; however, it is not known if these temporary LD changes which result from an LD growth test correlate with permanent noise-induced pathologies such as recruitment, discrimination problems or tinnitus. Perhaps the question of validity could be approached indirectly through the use of a more accurate classification of the previously noise-exposed subjects and the non-noise-exposed subjects. Subjects who had a previous history of noise exposure and had not experienced any of the pathologies associated with noise exposure could be classified as noise-resistant. If these subjects also demonstrated small changes in LD functions following noise exposure, an indirect measure of validity could be implied. An indirect measure of validity has been conducted in the form of a cross-sectional study of LD functions (Michael et al., 1978). Specifically, baseline LD functions were obtained on 60 subjects with a history of noise exposure and 60 subjects with no history of noise exposure. The result of this study demonstrated that the LD function for the noise-exposed group was significantly different from the non-noise-exposed group for increment magnitudes of 1 dB and lower. This difference was in the direction of the noise-exposed group identifying smaller increment magnitudes than the non-noise-exposed group.

This study investigated only some aspects of clinical feasibility, sensitivity, and reliability of an LD growth test. Continued research should be conducted in these areas before the LD growth test can be utilized effectively in an industrial hearing conservation program.

Related research has been done on the feasibility of obtaining LD functions as part of a test battery employing an industrial population (Schrock, 1979). This study demonstrated that reliable LD measures could be obtained on untrained listeners in a relatively short period of time.

Other parameters of the LD growth test procedure that should be investigated included a reliability measure obtained on untrained listeners. A baseline LD function was obtained on 60 untrained subjects in a study by Leslie Scott (1979). When these baseline LD functions were compared to the baseline LD functions on trained subjects, there was no significant difference between these two groups. Many of the subjects used in this study had participated in other listening experiments. If this test is to be used in an industrial setting, a reliability measure should be obtained on untrained subjects. This type of reliability would give insight into the difficulty of the task involved in the LD growth test.

As mentioned previously, the LDI obtained in Procedure B of Experiment III did not correlate with the Temporary Threshold Shift measure. Further investigations should be done to see if any audiometric test correlates with noise-induced LD changes. Some research has been done on the correlation of tinnitus with LD measures (Kennedy, 1979) and tone-on-tone masking with LD measures (Michael et al., 1978). However, continued research in this area may give insight into the way noise affects the auditory mechanism.

All of the subject groups used in this study were made up of both males and females under the age of 30 years. Scott (1979) found no sex

differences in the LD function with high level exposure. Bennett (1979) found some indication of sex differences in the LD measure at moderate levels of exposure. It would also be interesting to see if age or sex affected the LD function in this type of growth paradigm.

In the area of clinical feasibility of the LD growth test, further research is necessary to decrease the testing time required. Schrock (1979) found that the test time could be decreased by having the experimentor manually present the increment magnitudes for the LD function. Perhaps an accurate and meaningful LD function could be measured with two- or three-increment magnitudes. As demonstrated in this study, the largest LD shifts occurred at increment magnitudes between 0.2 dB and 1 dB. The test time could be reduced significantly if only a few increment magnitudes were used to characterize the LD function.

The test time could also be reduced if fewer five-minute exposures were used. That is, the subject's LD change could possibly be characterized accurately by using exposures that increase in 10 dB steps instead of 5 dB steps. Perhaps a greater change in the LD function would occur following exposures of a ten-minute duration instead of a five-minute duration. While this would increase the test time, it might produce larger LDI's and thus be a more sensitive measure.

Some interesting subjective responses of the subjects were noted following the noise exposure. Several subjects noticed that their post-exposure tinnitus, as well as the 4000 Hz test tone, appeared to change in pitch or quality with increased noise exposure. Possibly a study in which the subjects were asked to match the spectrum and

intensity of post-exposure tinnitus or a pure tone would provide some insight into noise-induced auditory changes.

It was interesting to note that the majority of subjects who noticed postexposure tinnitus judged it as being located in the ear contralateral to the exposed ear. This unusual finding is not without precedent (Scott, 1979). This subjective response may warrant further investigation.

It is necessary to validate the LD function through longitudinal studies which examine the correlation between the temporary noise-induced changes in the LD function and permanent noise-induced auditory impairment. Until such studies are undertaken, it can only be stated that 1) high level noise exposure results in temporary but significant changes in the loudness discrimination function at 4000 Hz, and 2) the noise-induced changes in the LD function appear to reflect auditory changes which occur independently of noise-induced threshold changes.

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APPENDIX A

Form Used for Recording Case History Information

Name______________________Date__________Recorded________Initial--------

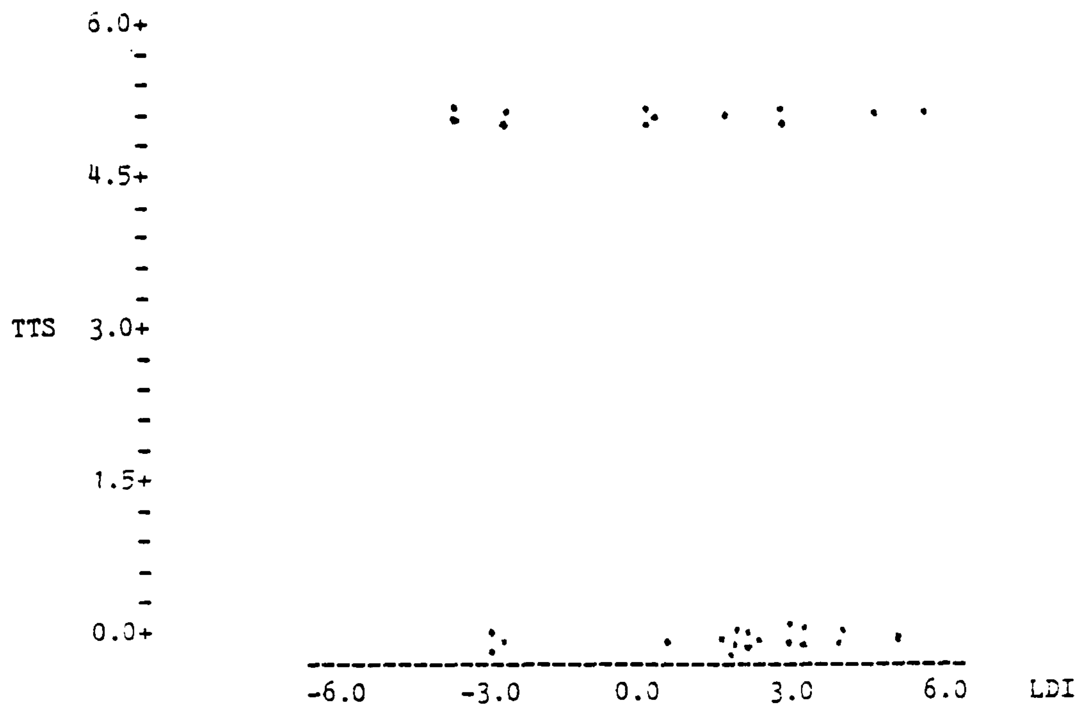
HISTORY	YES	NO	COMMENTS
1 Have you had a previous hearing test?			
2 Have you ever had hearing trouble?			
3 Do you now have any trouble hearing?			
4 Have you ever worked in a noisy industry?			
5 Do you think you can hear better in your Right ear? or Left ear?			
6 Have you ever had noises in your ears?			
7 Have you ever had dizziness?			
8 Have you ever had a head injury?			
9 Has anyone in your family lost his hearing before age 50?			
10 Have you ever had measles, mumps, or scarlet fever?			
11 Do you have any allergies?			
12 Are you now taking or have you regularly taken drugs, antibiotics, or mediation?			
13 Have you ever had an earache?			
14 Have your ears ever run? Right ear? Left ear?			
15 Have you been in the military service? Describe			
16 Have you been exposed to any sort of gunfire? Describe			
17 Do you have a second job? Explain			
18 What hobbies do you have?			

APPENDIX B

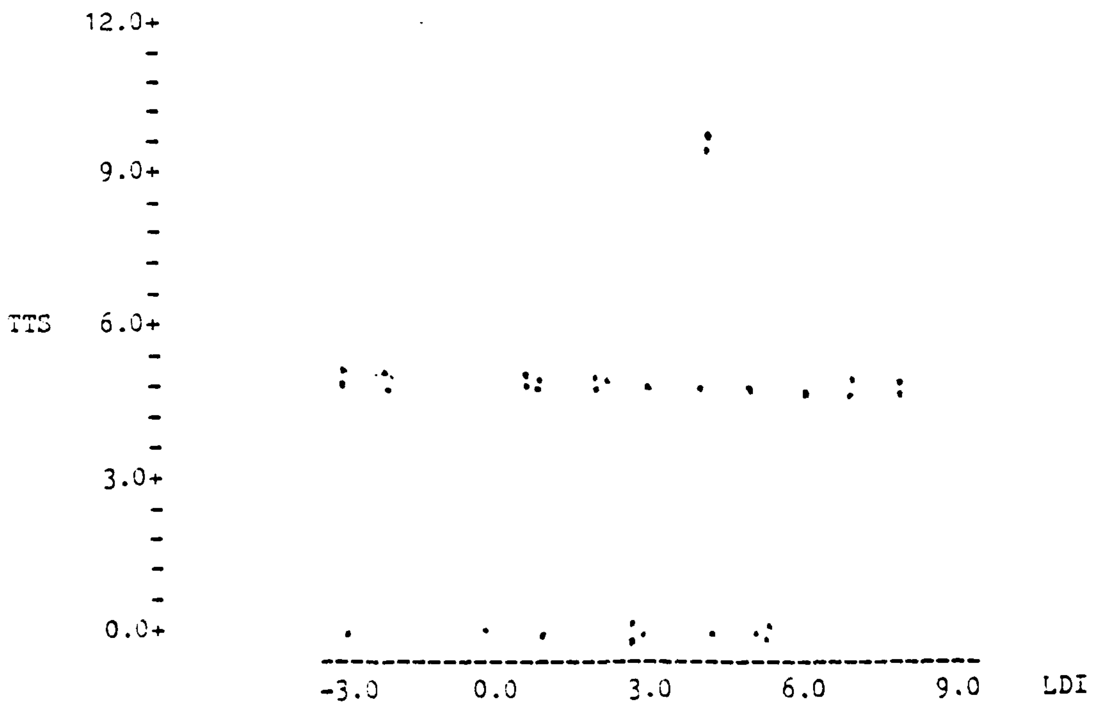
Scatterplots of LDI vs. TTS Data Obtained in Experiment III

Procedure A and Procedure B at Exposure Levels of 75 dB Through 100 dB

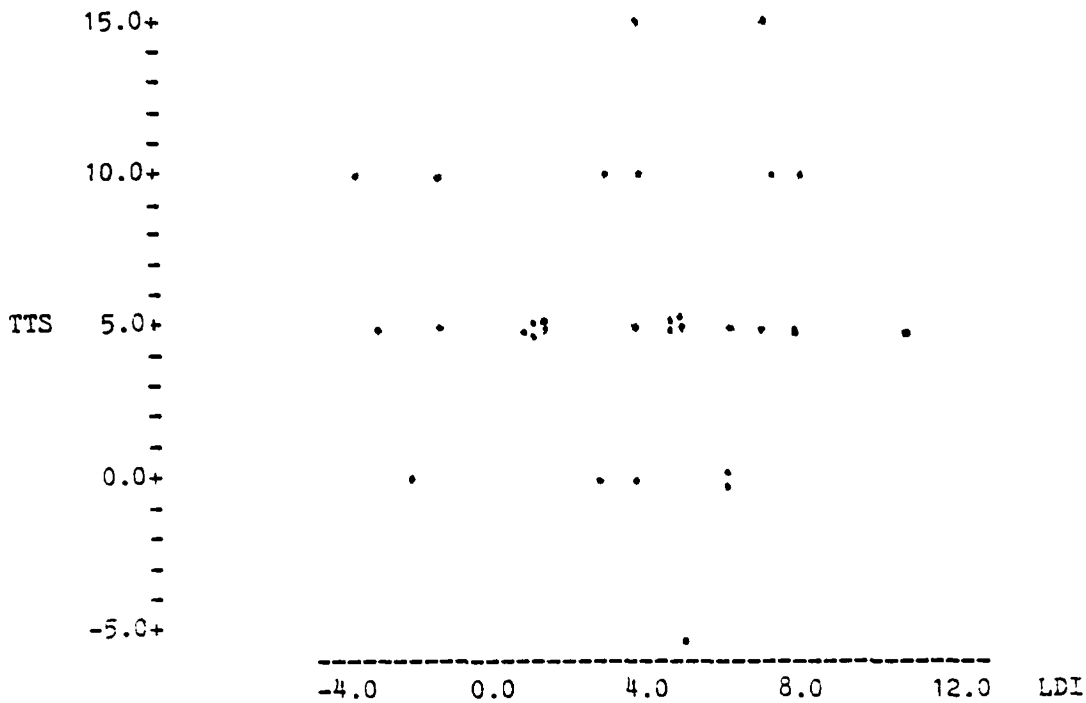
PLOT OF LDI VS. TTS FOR BROAD BAND NOISE, EXPOSURE LEVEL 75



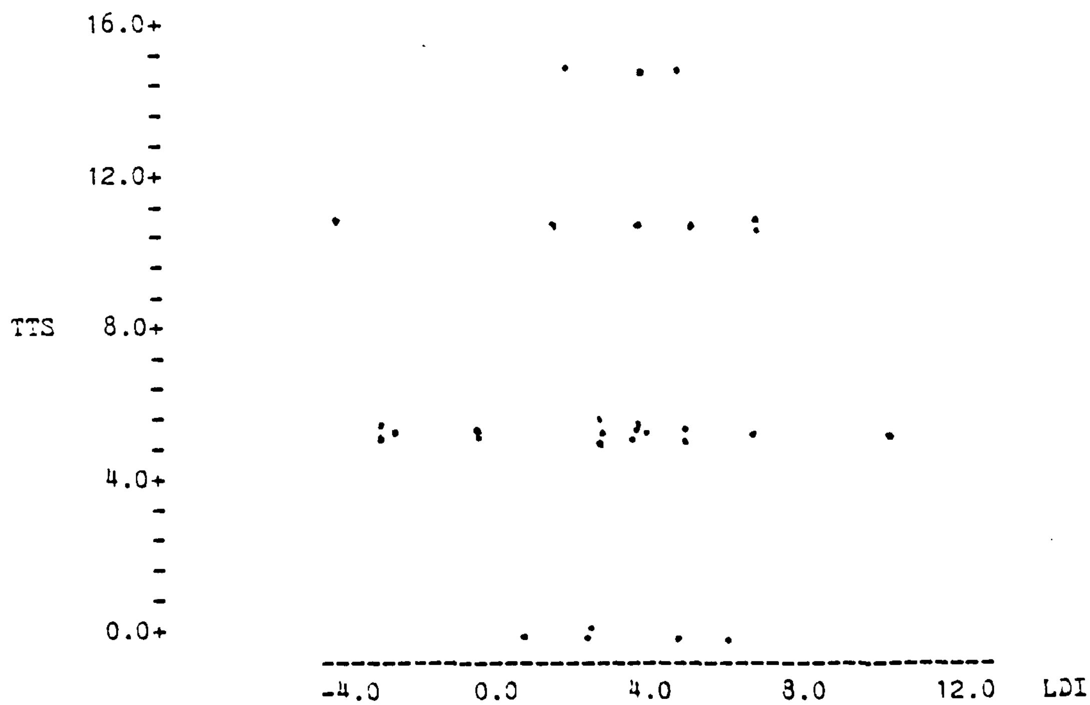
PLOT OF LDI VS. TTS FOR BROAD BAND NOISE, EXPOSURE LEVEL 80



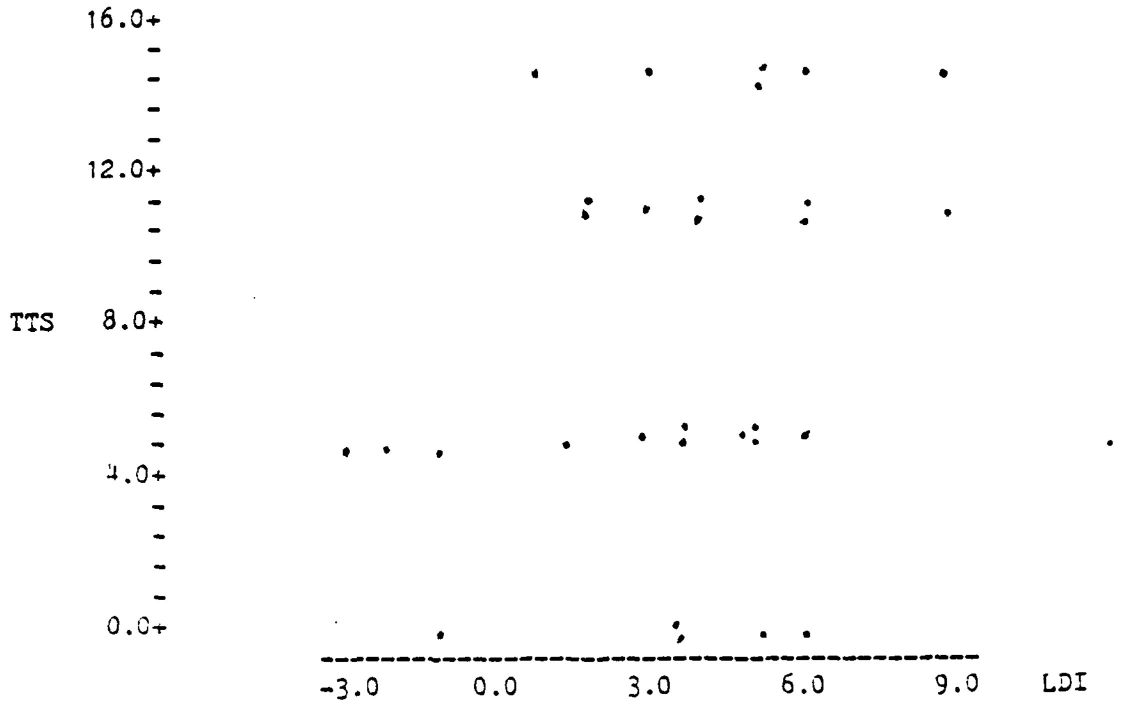
PLOT OF LDI VS. TTS FOR BROAD BAND NOISE, EXPOSURE LEVEL 85



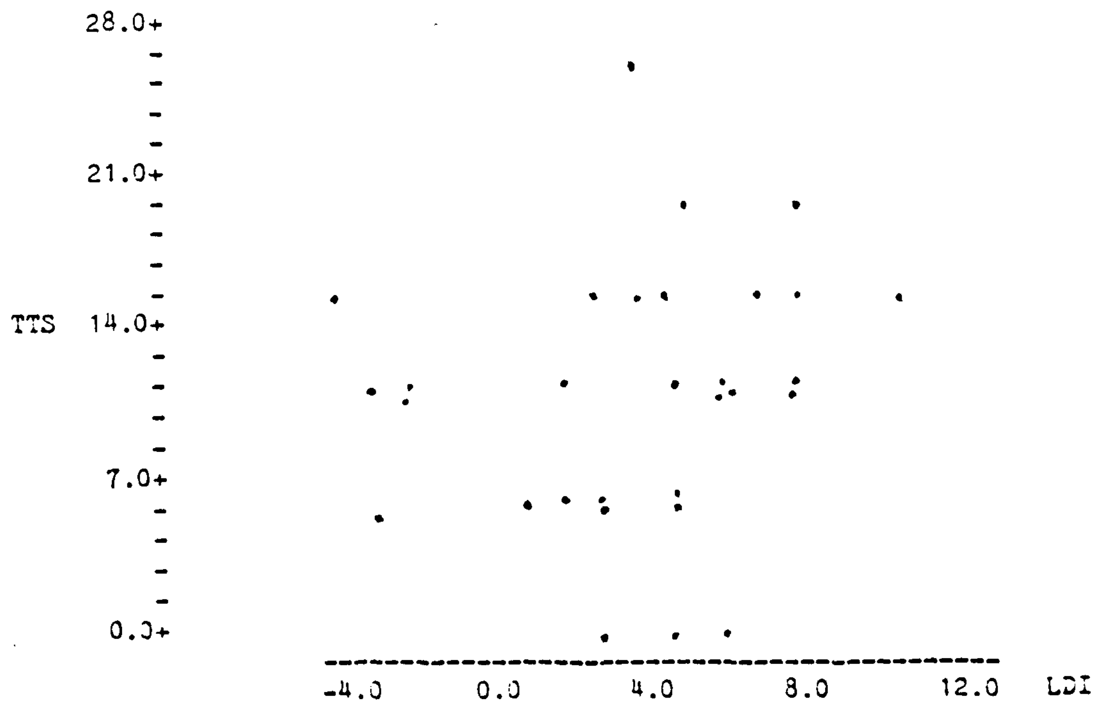
PLOT OF LDI VS. TTS FOR BROAD BAND NOISE, EXPOSURE LEVEL 90



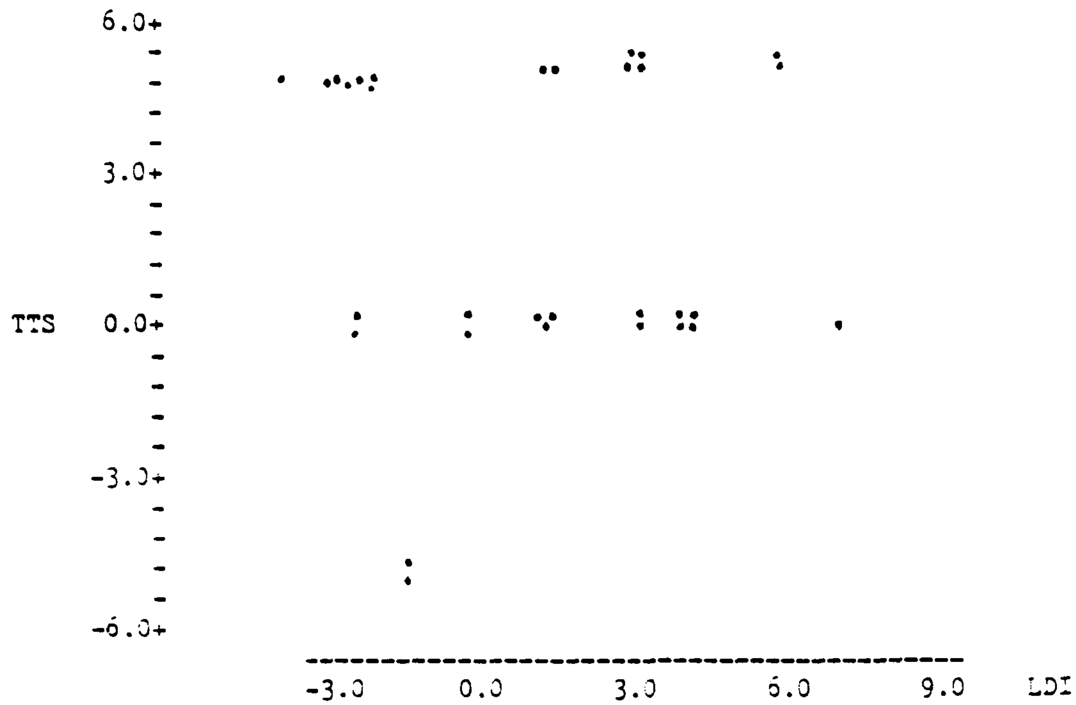
PLOT OF LDI VS. TTS FOR BROAD BAND NOISE, EXPOSURE LEVEL 95



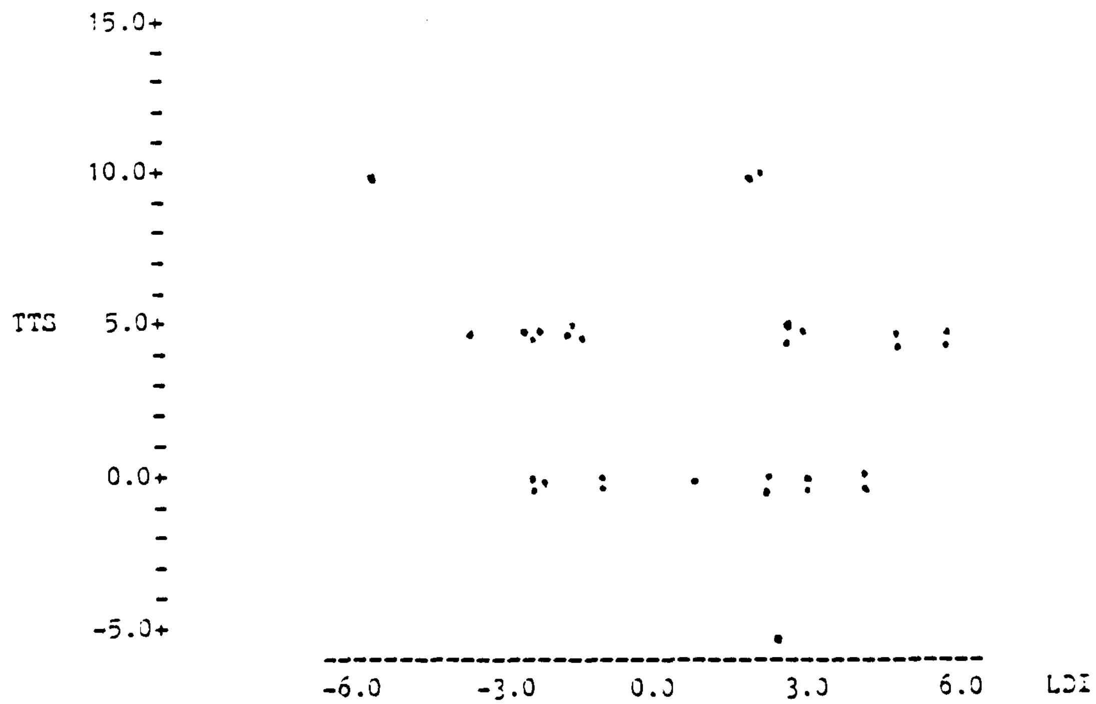
PLOT OF LDI VS. TTS FOR BROAD BAND NOISE, EXPOSURE LEVEL 100



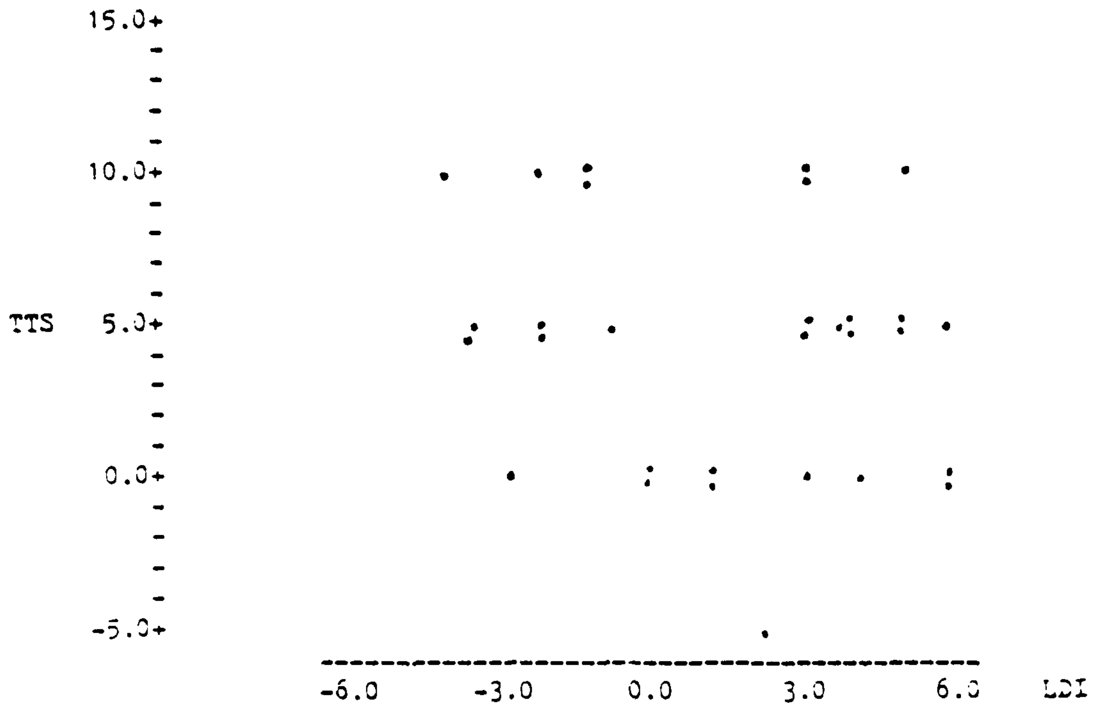
PLOT OF LDI VS. TTS FOR 2000 HZ, EXPOSURE LEVEL 75



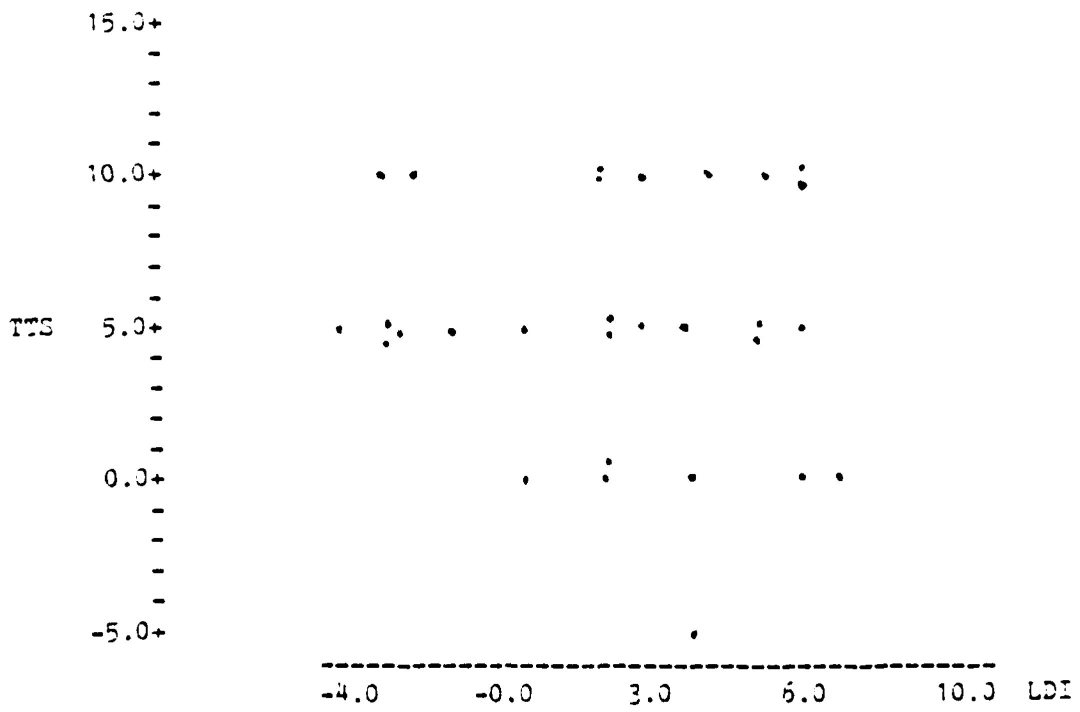
PLOT OF LDI VS. TTS FOR 2000 HZ, EXPOSURE LEVEL 80



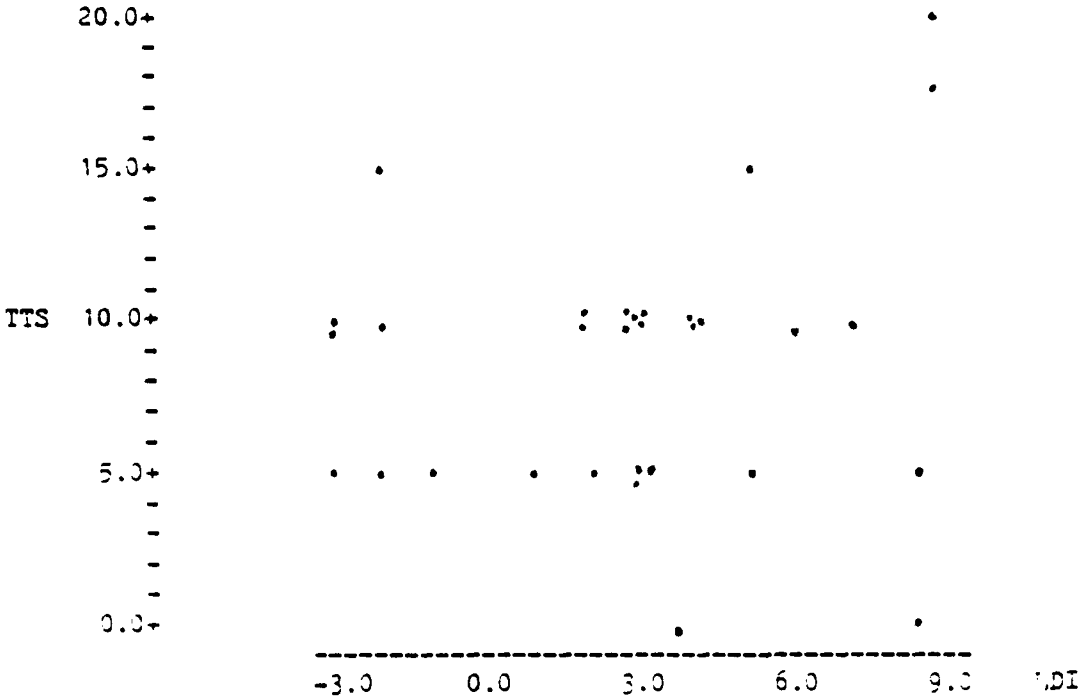
PLOT OF LDI VS. TTS FOR 2000 HZ, EXPOSURE LEVEL 85



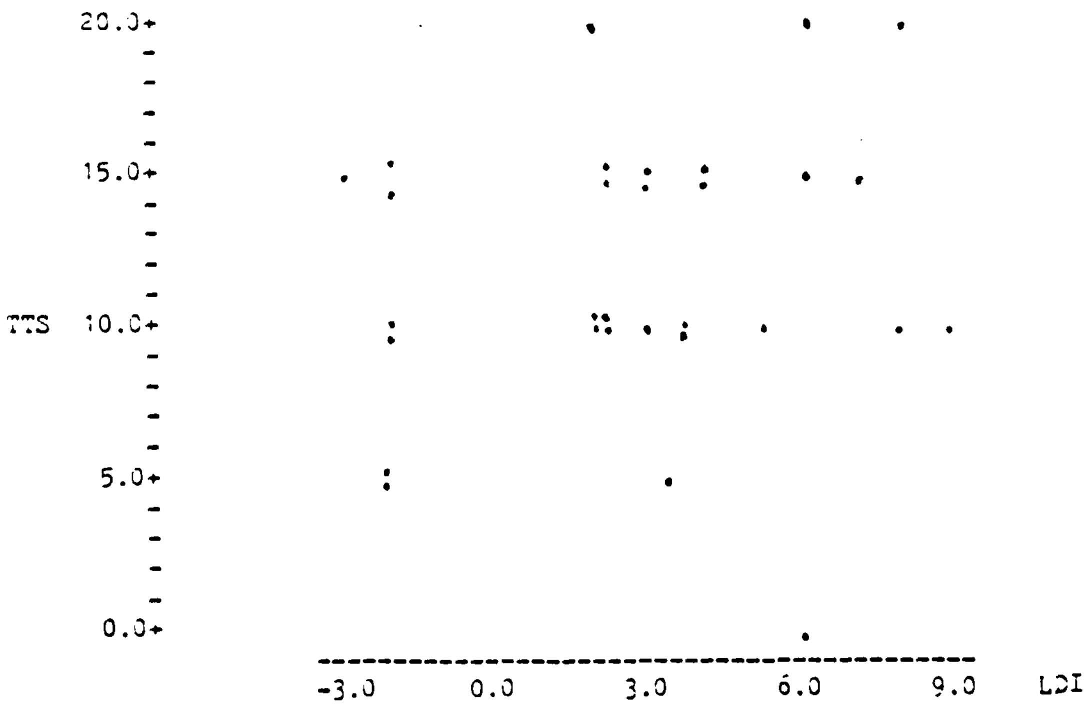
PLOT OF LDI VS. TTS FOR 2000 HZ, EXPOSURE LEVEL 90



PLOT OF LDI VS. TTS FOR 2000 HZ, EXPOSURE LEVEL 95



PLOT OF LDI VS. TTS FOR 2000 HZ, EXPOSURE LEVEL 100



APPENDIX C

Application of

Noise-Induced Changes in the LDI

The following is a proposed application of Experiment III results to a clinical test procedure that might be used to collect data on noise-induced changes in the LD function.

The benefit of using the LDI measure in this test procedure has been discussed previously (see Chapter IV). In Procedure B of Experiment III, the LDI data pooled across the 30 subjects appears to be distributed normally following noise exposures 80 through 100 dB SPL. The portion of the population which experienced the largest LDI following each of these noise exposures can be considered as being the most sensitive to a noise-induced auditory change in loudness perception. Those subjects that fall one standard deviation above the mean comprise the most sensitive 16% of the population. Table 27 is a list of the means and standard deviations of the LDI data collected in Procedure B of Experiment III.

Thus, if a subject obtained a positive LDI score on the LD growth test previously described greater than the numbers listed in Table 28, he/she can be considered as being in the 16% which is most sensitive to a noise-induced hearing change, based on the subject pool for this experiment. The LDI score is the largest difference score between the pre-exposure and post-exposure LD function for each exposure level. These LD function scores are whole numbers referring to increments (out of ten) correctly identified. Thus, the LDI values listed in Table 28 should be rounded off to the nearest whole number to be clinically practical. Therefore, a subject could be considered sensitive to noise-induced auditory changes in loudness perception if the post-exposure LDI scores exceeded the numbers in Table 29 for the respective

Table 27. LDI Data Averaged Across 30 Subjects' Exposure Levels

	Exposure Level (dB)				
	80	85	90	95	100
$\bar{X}$	2.40	3.45	2.50	3.33	3.77
SD	2.96	3.08	3.10	2.72	3.40

Table 28. LDI Scores for Exposure Levels

	Exposure Level (dB)				
	80	85	90	95	100
LDI	5.36	6.53	5.60	6.05	7.17

Table 29. LDI Values That Identify 16% of the Population Most Sensitive to Noise-Induced Changes in LD

	Exposure Level (dB)				
	80	85	90	95	100
LDI	5	6	6	6	7

exposure levels. These numbers would apply only to LD changes induced by the test procedure outlined in Experiment III, Procedure B. That is, the test would begin with a five-minute exposure to broad band pink noise at 75 dB(A). The LD function would be measured 30 seconds post-exposure at 50 dB HL and 4000 Hz. This post-exposure LD test would begin with the smallest increment magnitude at which the subject could identify all the increment magnitudes before the noise exposure.

Following this LD measurement, the subject would be exposed to a broad band pink noise at 80 dB(A) for five minutes, after which the same post-exposure LD test sequence would be administered. This procedure would be repeated five times, with an increase in the exposure tone of 5 dB(A) for each trial until an exposure of 100 dB(A) is reached or until the subjects' LDI exceeds the respective numbers listed in Table 29.

When this sensitivity criteria is applied to the subjects used in Experiment III, six subjects are identified as being "sensitive" to noise-induced changes in loudness discrimination. Table 30 lists these subjects and their respective LDI scores. Six subjects represent 20% of the population used in this study. It should be noted that the LDI for subject number 7 exceeded the "sensitive" LDI value at only one exposure level and is below the "sensitive" LDI value at all other exposure levels. Thus, the large LDI obtained following the 95 dB exposure level for this subject may be an erroneous score. All of the other subjects showed large LDI scores following several exposure levels. This LD growth test should be standardized on a larger sample that more accurately reflects the persons found in the environment in

Table 30. Subjects Identified as being Sensitive to Noise-Induced LD Changes

	Exposure Level (dB)				
	80	85	90	95	100
Subject No.	LDI Scores				
4	7	8	5	4	7
7	4	5	3	3	4
15	6	6	5	6	6
21	7	10	10	8	8
27	6	7	6	6	10
28	5	7	2	6	6

which it will be used (i.e., untrained listeners). Until this is standardized on such a population, it can only be stated that these critical LDI values can be applied to subjects who fit the profile of the subject pool for Experiment III.

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